MOTOROLA

COLOR

TELEVISION

Fundamentals of color television

color television training course

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INDEX

Page

1 / The Nature of Light

Light is considered to be electromagnetic energy similar to radio and television signals. It obeys similar laws. All electromagnetic radiations with wavelengths between .00004 and .00007 centimeters appear as light. Because these decimal fractions are rather cumbersome to work with, a smaller unit—millimicron—is used to express wavelength of light. A millimicron is one thousandth of a millionth of a meter. Therefore, visible light can be expressed as having wavelengths between 400 and 700 millimicrons.

Figure 1-1 is a graphic presentation of the total electromagnetic radiation spectrum showing the location of the wavelengths we call light. At the left-hand side, low frequency audio vibrations are shown and as you progress to the right-hand side, the wavelengths get shorter (frequency increase), spanning the radio, television and microwave regions.

Next is infrared, where heat radiation takes place, and then the frequencies which represent visible light. The extreme right-hand portion is the domain of X-rays, gamma-rays and cosmic-rays.

If we examine the visible light portion closely, as illustrated, we see that each individual wavelength (or frequency) of visible light corresponds to a definite color.

White light contains all of these wavelengths. We can demonstrate that white light is composed of all colors by the use of a glass prism. Figure 1-2.

As the white light enters the glass of the prism, it is going from one transmission medium to another. This will cause a bending of the light ray, and the amount of bending is governed by the refraction index of the glass and the wavelength of the light. Since the refraction index is different for each wavelength of light, it is noted that the long wavelengths, or the red colors, do not bend as much as the shorter wavelengths or the blue colors. The prism separates all components of light by wavelength and indicates that white light is made up of all wavelengths of color light.

It is possible to reverse the process and create white light by re-combining all the colors in the above spectrum.

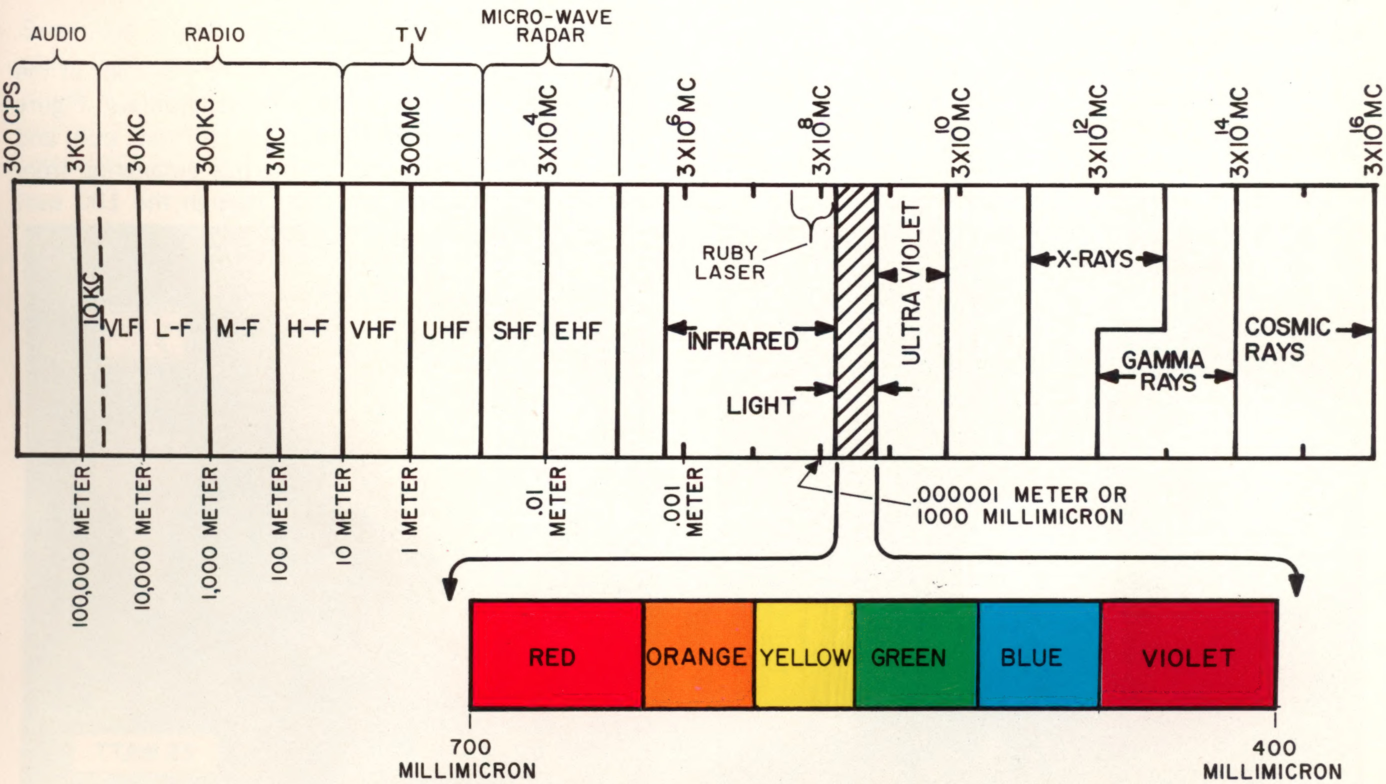


Figure 1-1. Electromagnetic Radiation Spectrum

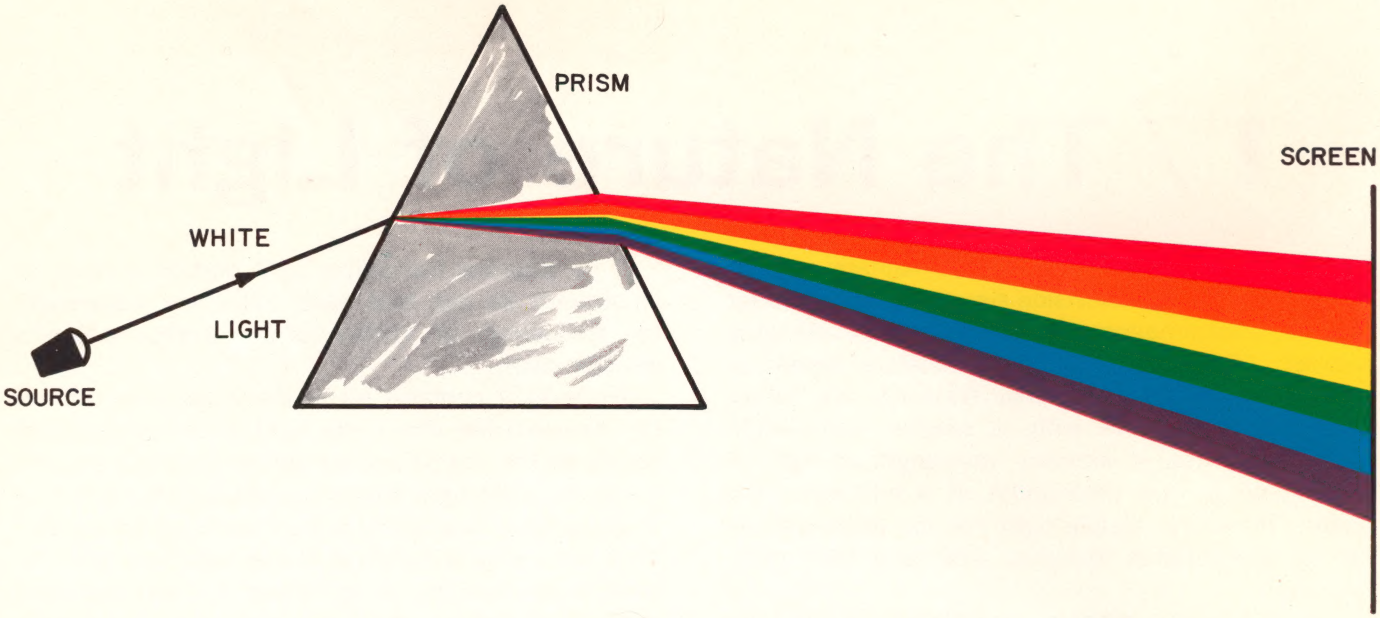


Figure 1-2. Separation of White Light

It is also possible to take only three colors and combine them to produce a white light. By taking a color from each end of the spectrum and one from the middle, and mix them together, a white light will result. Figure 1-3.

Characteristics of Light

There are three characteristics by which we can define any source of light that we can observe. These are Brightness, Hue and Saturation. If we know these three things, we can reproduce a source of light at any time or place.

Brightness

Brightness is defined as the amount of light, or the amount of energy, reaching the eye from the scene, and independent of all other considerations.

Figure 1-4 shows two light bulbs, each giving off a white light. The 100 watt bulb gives four times the brightness, or energy output, as the 25 watt light bulb and would appear to the eye to be four times as bright. A calibrated photo cell and meter would give the same indication.

Hue

Hue is defined as the wavelength or the color of the light, regardless of all other considerations. Figure 1-5 shows two red light bulbs, a 100 watt bulb and a 25 watt bulb. The color or the hue emanating from these bulbs is identical, even though the 100 watt

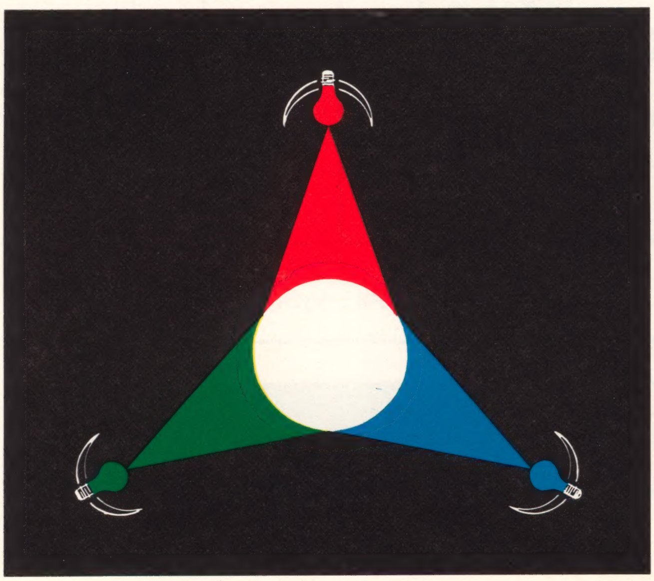


Figure 1-3. Additive Primaries

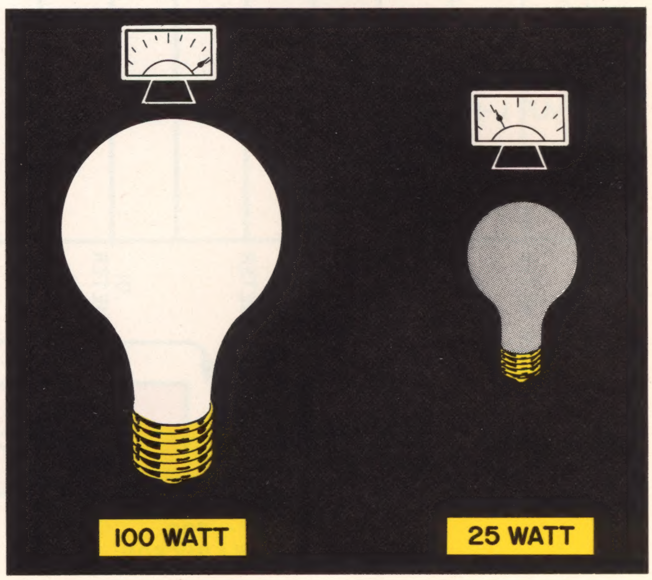


Figure 1-4. Brightness

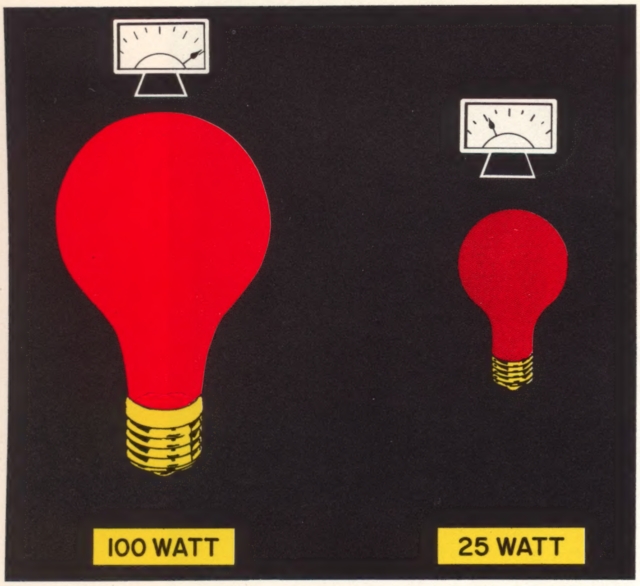


Figure 1-5. Hue

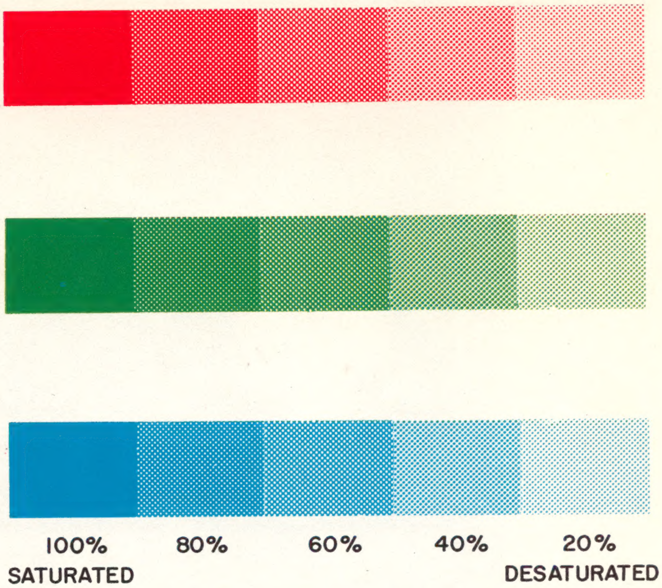


Figure 1-7. Desaturation Scale

light bulb is putting out roughly four times as much energy as the 25 watt bulb. The characteristic here is that they are giving off the same wavelength of light.

An analogy of this would be two radio transmitters, both of them transmitting on 700 Kc, but one of them having an output of 100 watts and the other 25 watts. Even though the output energy is different (BRIGHTNESS), the wavelength of the radiation (HUE) is the same.

Saturation

Saturation is defined as the absence of dilution with white light, or the pureness of the color. Figure 1-6 shows a fully saturated red beam of light being intersected by a pure white beam of light. Where the two beams intersect, we show a color which we know as pink. Pink is a desaturated red color and would be identified here as a pastel shade, as would all desaturated pure colors.

Figure 1-7 shows three different hues in various percentages of saturation. At the left, the colors are 100% saturated and become less saturated as they progress to the right.

Characteristics of the Eye

The human eye has two characteristics that are important to consider when designing a compatible color television system. First, we do not see all colors in the same proportions. Figure 1-8 illustrates that if we have four 100 watt light bulbs, and each a different color, but each one radiating 100 watts of light energy, the eye would "see" these as different amounts of light output.

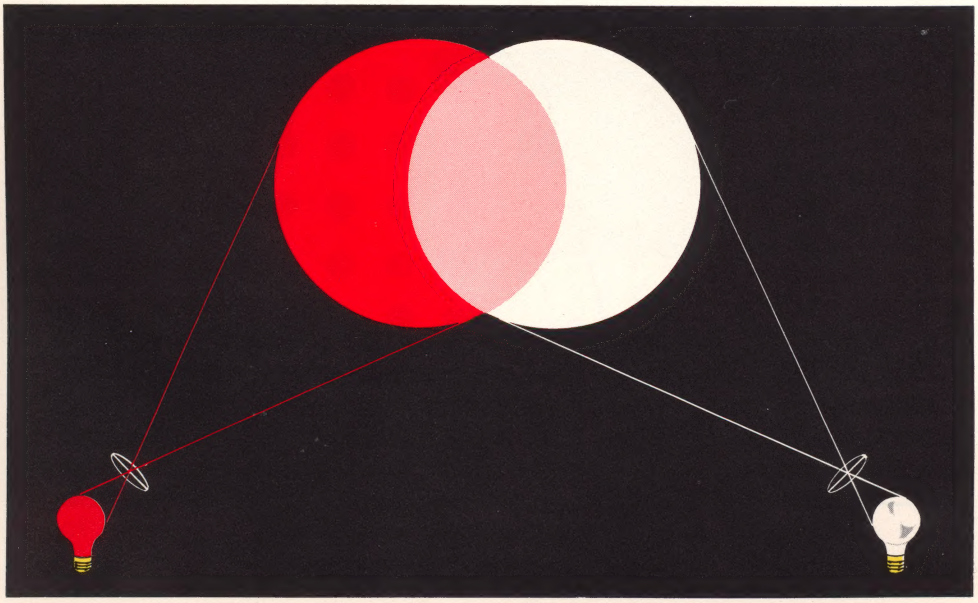


Figure 1-6. Saturation

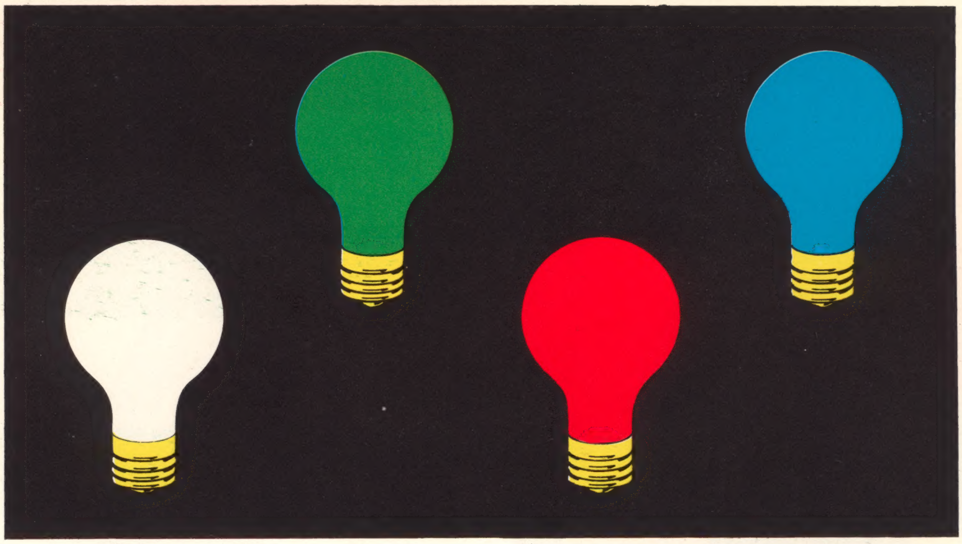


Figure 1-8. Brightness Response of the Eye

The white bulb would appear the brightest, the green 59% as bright, the red 30% as bright and the blue only 11% as bright as the white bulb. This can be plotted graphically as shown in Figure 1-9.

Figure 1-9 shows a bandpass response curve of the eye, which relates the amount of stimulation at the optic nerve to the wavelength of light being observed. This tells us that the maximum response, or stimulation to the eye, takes place in the green-yellow region, which is about 555 millimicrons wavelength. There is a lesser response in the blue and red regions, which make these two colors appear less bright than green.

The second characteristic of the eye that we are concerned with, is that its ability to resolve fine detail varies with the color observed. Figure 1-10 shows that the power of the eye to resolve detail is poorest in the blue region, slightly better in the red and green regions, but the best of all in the white region. The same characteristic can be explained in another way.

Figure 1-11 shows that color identification becomes more difficult as the size of the color area is reduced. What this means is that color is seen only in large areas and not as fine detail. In the

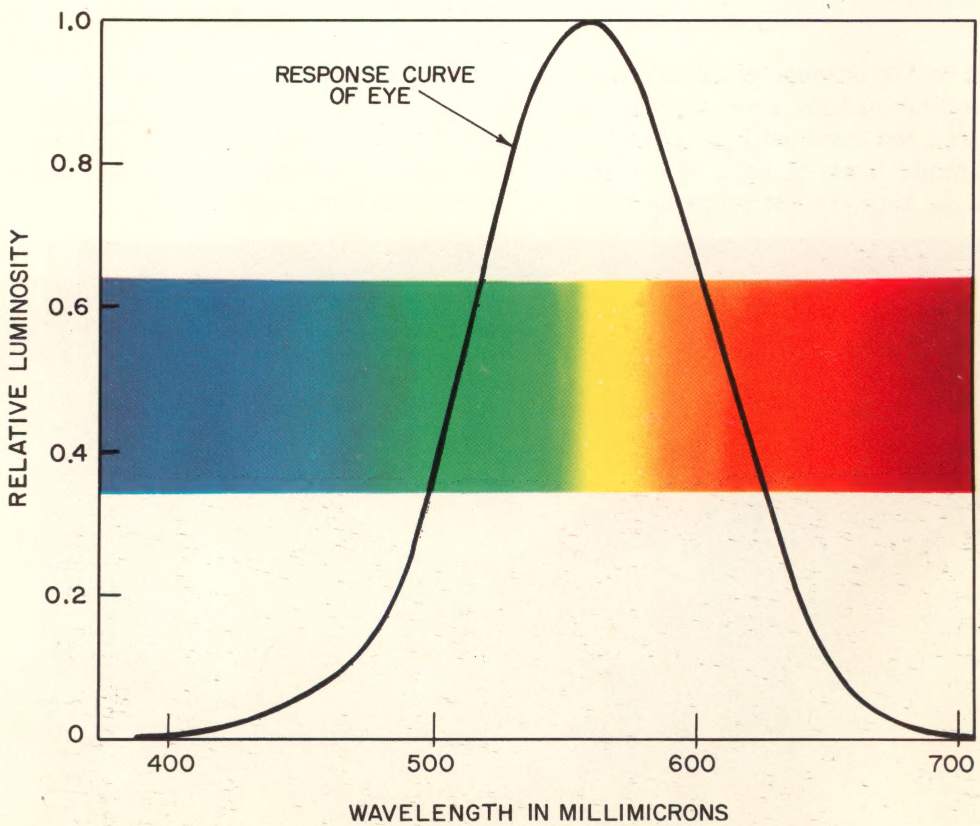


Figure 1-9. Bandpass Response Curve of the Eye

Figure 1-10. Color Resolution

illustration, we see that the large dots on the left side are easily identified as color, but become increasingly difficult to define as color as we get to the small block on the right.

As colored objects are reduced in size, four things are found to happen in succession; First, blues become indistinguishable from grays of equivalent brightness.

Second, yellow becomes indistinguishable from grays. In the size range where this happens, browns are confused with crimsons, and blues with greens, but reds remain clearly distinct from the blue-greens. On the whole, colors with pronounced blue lose blueness, while colors lacking blue, gain in blueness; all become less saturated.

Third, with still further decrease in size, reds merge with grays.

Finally blue-greens also become indistinguishable from gray. This can be restated as concrete values as shown in Figure 1-12.

A normal eye can perceive fine brightness detail whose individual elements subtend 0.5 to 1.0 minutes of arc. At 10 ft., this would be an object between 1/32″ and 1/64″ cross-section.

A normal eye can perceive color detail (unaccompanied by brightness change) with areas subtending an average of 5.5 minutes of arc. At 10 ft., this would be an object about 3/16″ across.

This means that the eye can perceive brightness detail in areas 5 to 10 times smaller than it can color detail. In Figure 1-11, as the dots become smaller, they lose their identification as colors, but still could be distinguished as dots, in terms of brightness (shades of gray) only.

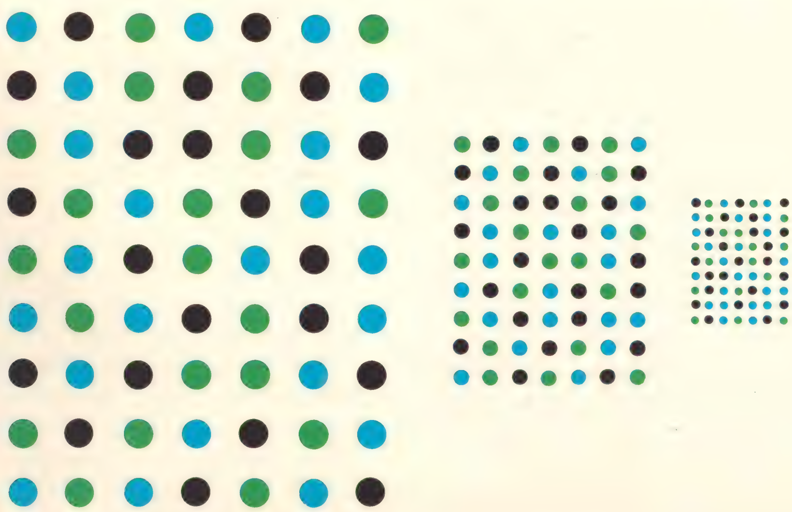


Figure 1-11. Color Perception In Small Areas

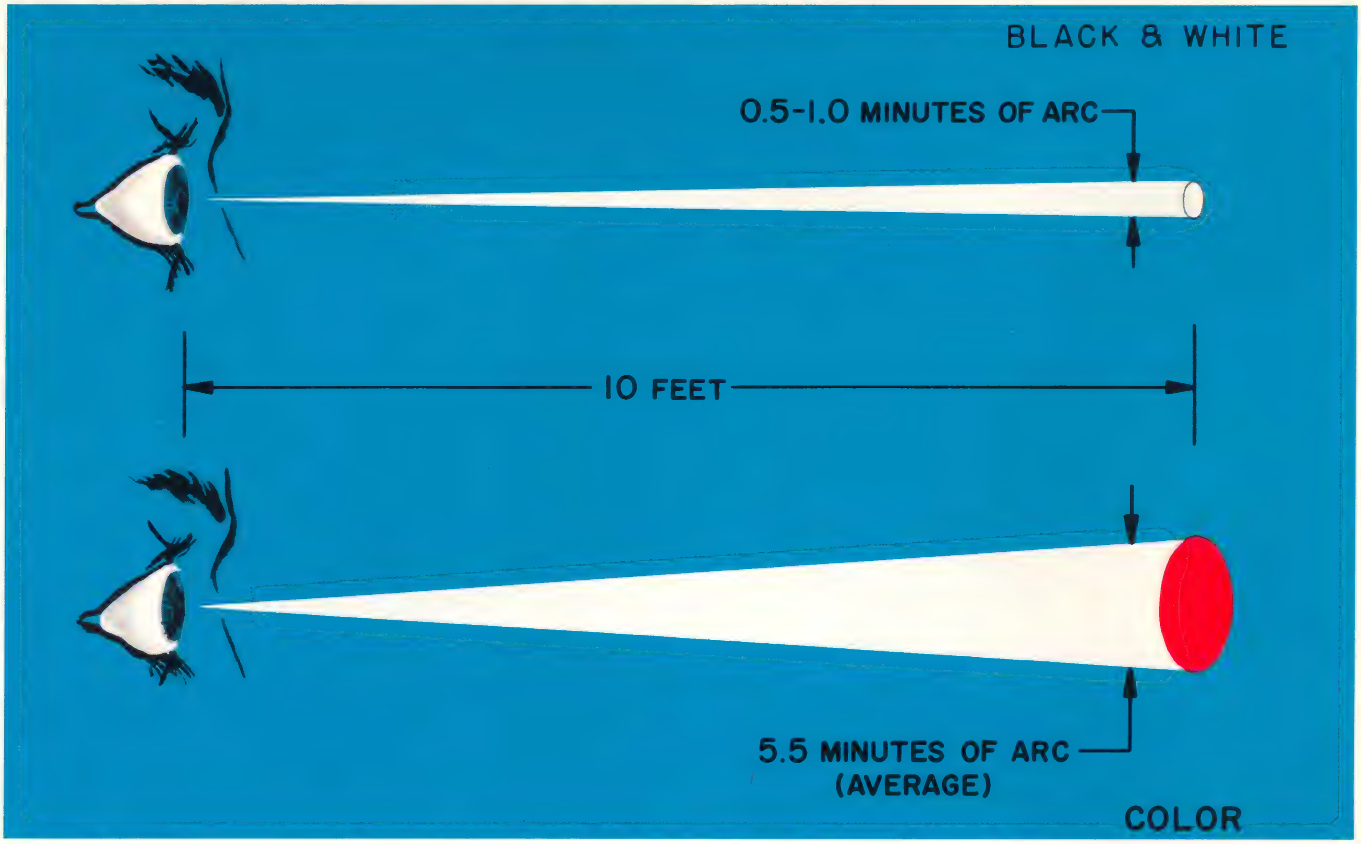


Figure 1-12. Perception of Eye to Small Detail

Summary

In order to transmit a color picture, we must transmit brightness, hue and saturation information. But to make the transmission compatible with existing black and white receivers, we must also take into account the characteristics of the eye. This means that the black and white receiver should see the various colors as shades of gray (brightness) and there be no deterioration of detail in the black and white picture.

As pointed out earlier, the eye sees fine detail only as degrees of brightness. We can then transmit the brightness component of the color scene, with all the fine detail as a separate signal; and transmit the hue and saturation information as a separate signal. Because the eye does not see fine detail as color, the hue and saturation signal can be transmitted as a reduced bandwidth subcarrier, which in practice, is about .5 mc wide. Figure 1-13 illustrates how these can be transmitted separately and produce a compatible black and white picture. A black and white receiver tuned to this transmission would respond only to the brightness signal since there are no provisions for receiving the color subcarrier.

Now let us summarize what we have discussed thus far. The three characteristics of light which define any light source we can produce or observe are—brightness, hue and saturation. Figure 1-14. We must transmit a signal which represents these three qualities of our scene if we are to reproduce it accurately at the receiver.

Brightness is defined as the amount of energy or light reaching the eye from the scene, regardless of any other consideration.

Hue is the wavelength or the color of the light reaching the eye regardless of its brightness or intensity.

Saturation is defined as the freedom of dilution with white light, or the pureness of the color.

We found that the eye has a bandpass characteristic curve which is another way of saying that the optic nerve is excited to a greater degree by some colors than it is others. The brightness response is the greatest in the yellow-green region and the poorest in the extreme blue and red regions. This means that we have to transmit different brightness levels for each color in the scene in order to make our system compatible to black and white sets.

We also found that the eye sees very little resolution or detail as color, having its maximum response to detail as black and white or in terms of brightness. This means that fine detail need only be transmitted as brightness information, allowing us to transmit hue and saturation information as a narrow bandwidth or low resolution signal.

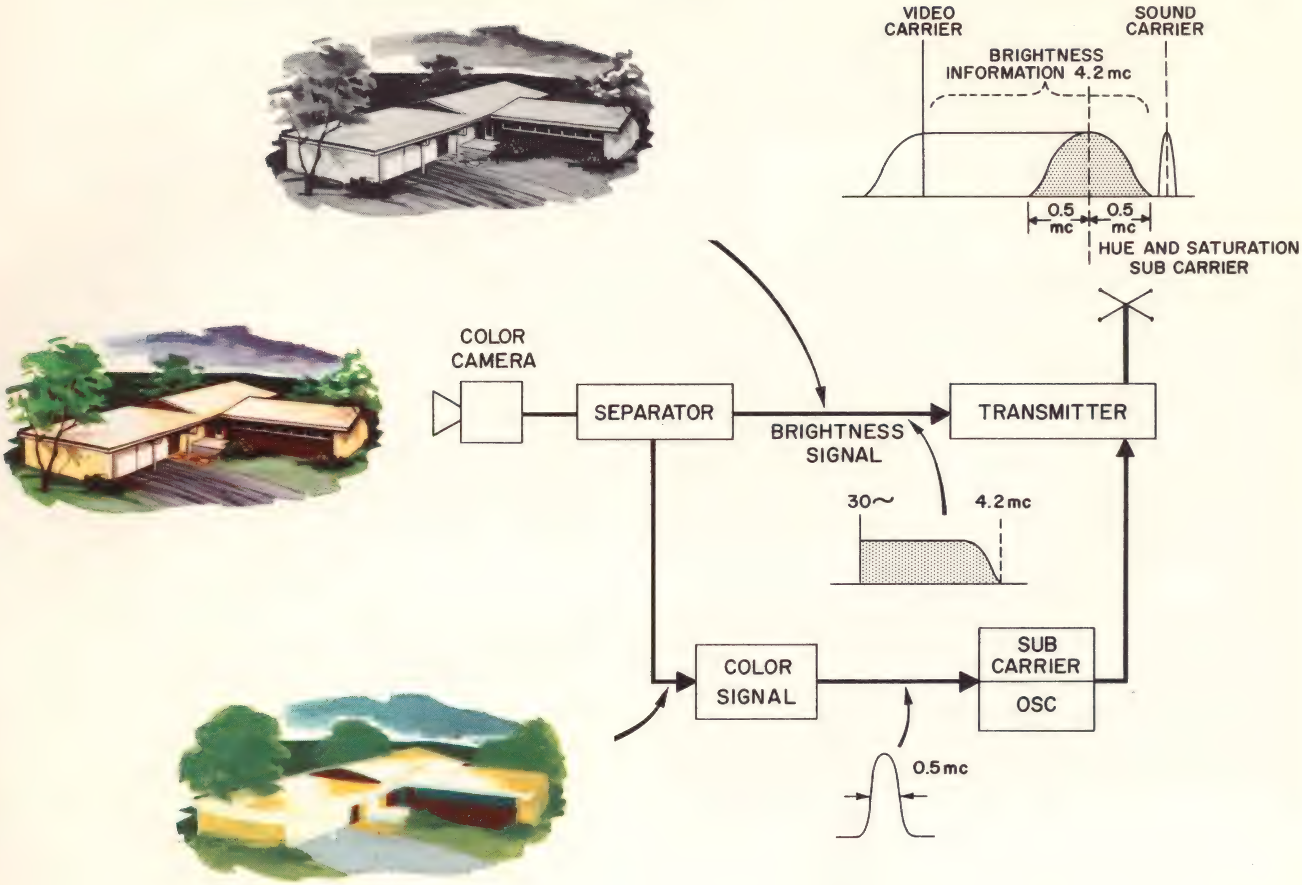


Figure 1-13. Components of Color Signal

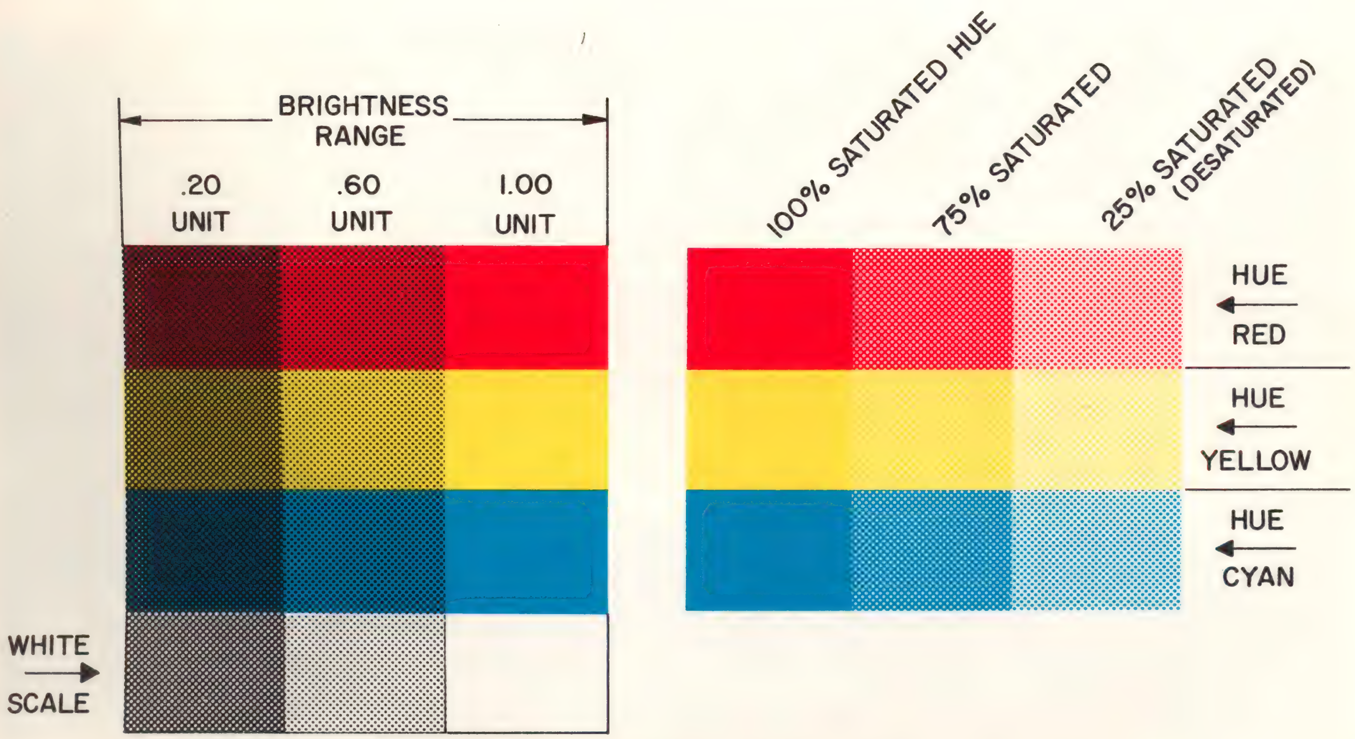


Figure 1-14. Hue, Brightness and Saturation

Combining Primary Colors

If we take the three primary colors, red, blue and green, and combine them in proper amounts, we can produce white. By combining different combinations of any two of the fully saturated primary colors, we can produce yet other colors, as illustrated in Figure 1-15.

Figure 1-15. Combining Primary Colors

Here we can see by combining green and blue, we obtain cyan. By combining red and green, we can produce yellow, and by combining red and blue, we can produce magenta. The center area where all three colored lights converge, white light is produced. The yellow, magenta and cyan colors illustrated here would be defined as complimentary colors since they are produced by combining two of the primaries with the absence of the third primary. Yellow would be the complimentary color of blue, indicating that it was white light with all of the blue light removed. Magenta would be the complimentary color of green, being composed of white light with all green light removed, and cyan would be the complimentary color of red. It can easily be seen at this point, that by varying the intensities of these three primary hues, we can reproduce almost any color that the eye can detect. This means that we have to concern ourselves with only three colors in order to produce a full color transmission.

Reflected Light and Filters

Let us take four objects, as seen in Figure 1-16, and illuminate them with a source of white light. As seen here, we have one white object, one red, one green and one blue.

Since, as we have determined earlier, white light contains all colors of light, there will be reflected back to you, the observer, the characteristic colors of the objects. The blue object will absorb all colors of light except the blue which is its characteristic color, and will reflect blue back to your eye. The

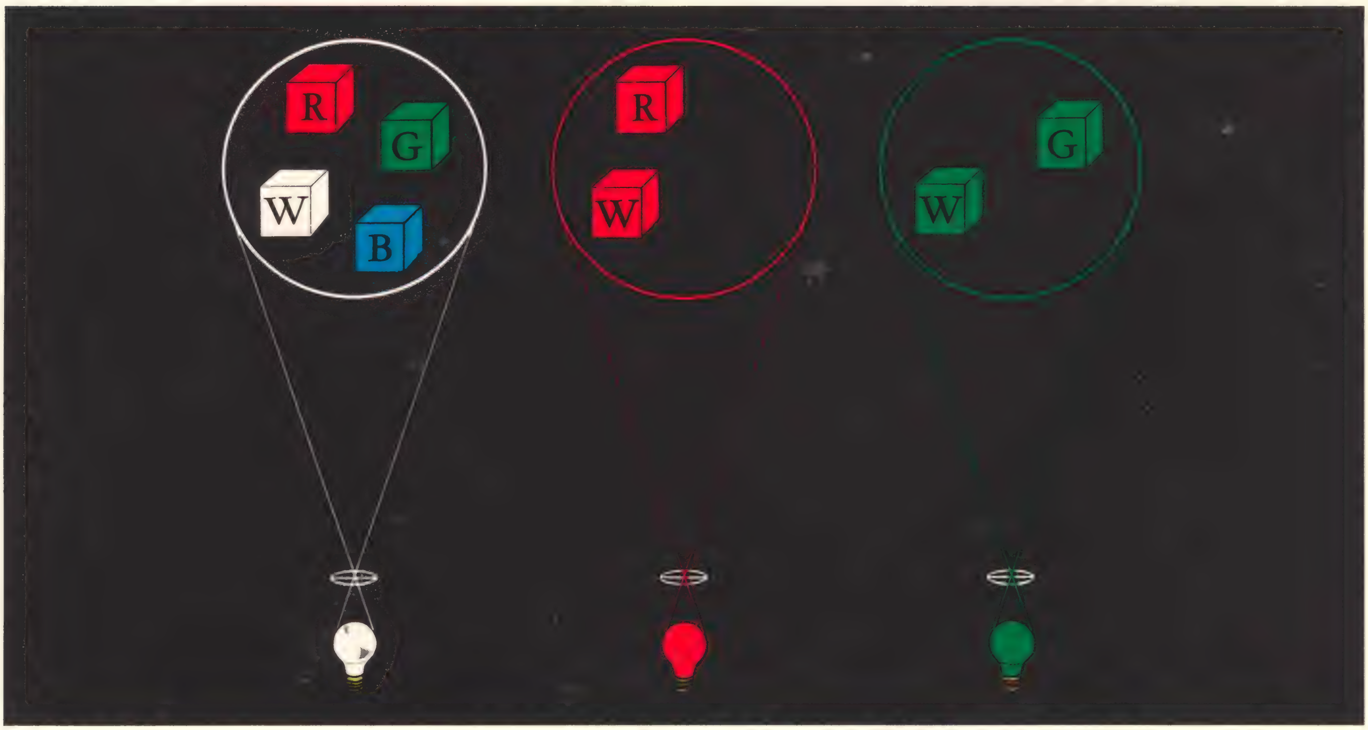


Figure 1-16. Light Reflection By Colored Objects

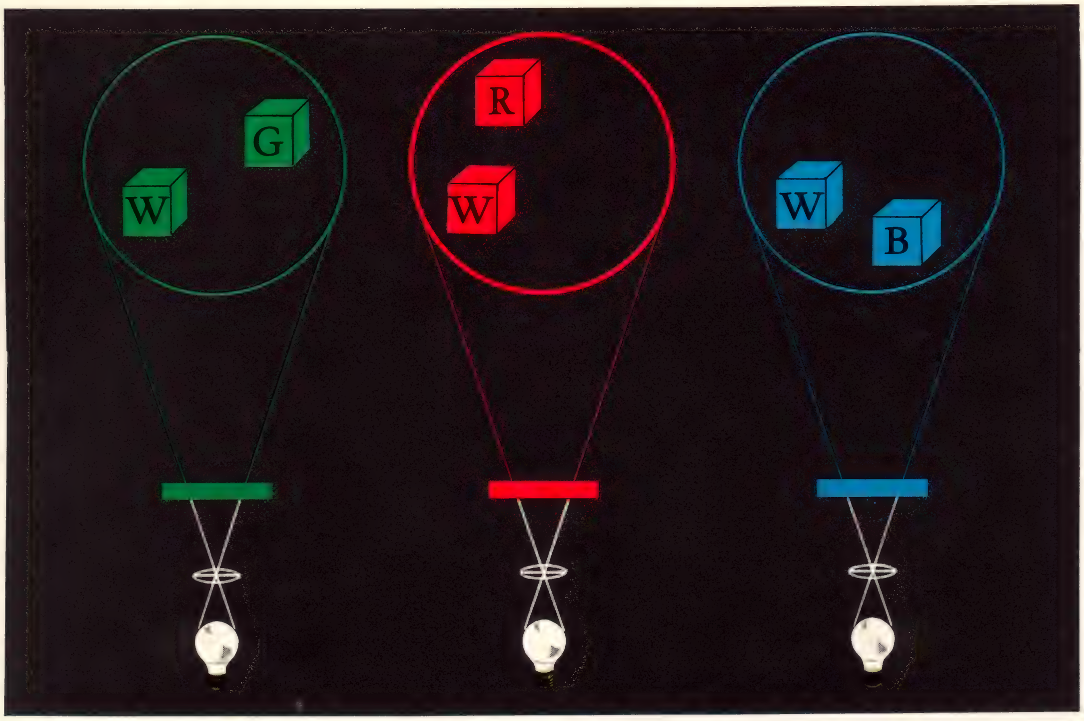


Figure 1-17. Light Filters

green object will absorb all colors of light except the green color and reflect it back to you. The red object will absorb all colors of light except red and reflect red back to your eye. The white object will reflect all colors back to the eye and this will be seen as white.

The center illustration of Figure 1-16 shows what would happen when the same four objects are illuminated by red light. Since the blue object absorbs all color lights except blue, it would absorb the red light falling upon it and would appear to be black or not visible.

The green object absorbs all colors except green, and since it is being illuminated by red light, it would absorb this red light and would appear to be invisible. Since the red object reflects only red light and absorbs all other colors, it would reflect back to the observer its natural red color. The white object, since it reflects all colors, would reflect back to the observer a red color, since red is the only color light which is falling upon it.

Now we can make the same illustration with green light falling upon the scene. This time, the red and blue objects would appear to be invisible since they would absorb the green light, while the green and white objects would reflect back the green light.

It is also possible to obtain the same effect by using white light sources and colored filters instead of colored light sources. Figure 1-17 shows such an arrangement. A filter is a transparent material which will filter out, or absorb, all colors of light except one particular hue. The action is the same as a band-pass filter. A green filter would absorb all colors except green and let green pass through readily. This makes it possible to have a source of white light and place in its path a filter of the desired color. In the left-hand illustration, we have placed a green filter in the path of the white light source and are illuminating the original scene by this green filtered light. We will have the same effect with the green filter as if we had illuminated the scene with a green light bulb. The red and blue objects will appear to be invisible since they absorb green light, while the white and green objects will be visible since they will readily reflect the green light.

By using a red filter as in the center illustration, we notice that only the red and the white objects are visible since the green and blue objects will absorb the red light. On the left side, we notice that when we use a blue filter in the path of the white light, only the white and the blue objects are visible, since both will readily reflect blue light.

If we were to illuminate the original scene in Figure 1-18, with three different sources of color light, one green, one red and one blue, we would see this scene in its original colors. The green and the white objects would reflect back to the observer, the green components of the scene, the red and the white objects would reflect back to the observer the red components of the scene, and the blue and the white objects would reflect back to the observer the blue components of the scene. We learned earlier in this discussion that white could be re-created by combining the proper amounts of the three primary colors, green, red and blue, so by reflecting back to the eye these three colors super-

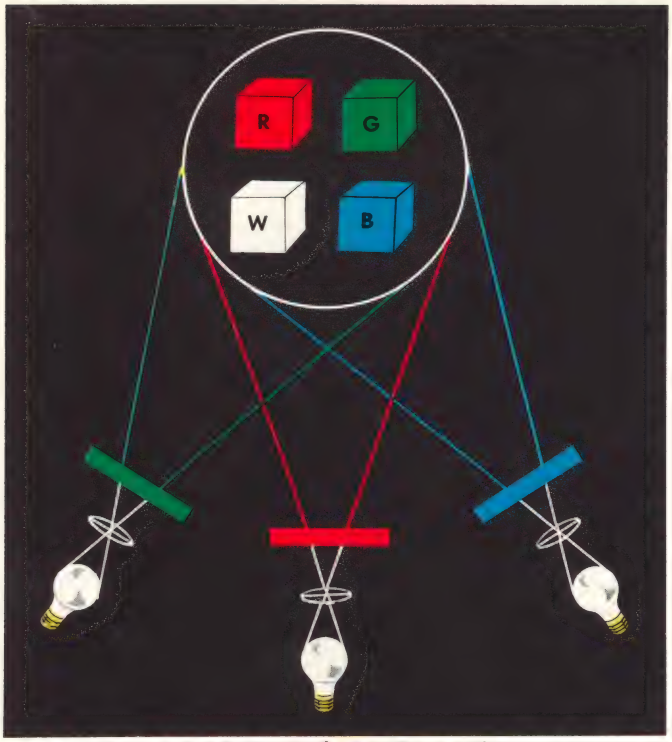


Figure 1-18. Reproducing Original Scene

imposed upon one another, we see the object as white. If white were given a brightness factor of 100%, red would appear to be 30% as bright, green 59% and blue 11% as bright.

Figure 1-19 shows the original scene illuminated by white light and in place of a light bulb behind the filter, we place a human eye. The eye behind the green filter would only see the green components of the scene, which would be the white and green objects, seen as green. The eye behind the red filter would see the red components of the scene only, which would be the red object and the white object, seen as red; and the eye behind the blue filter would see only the blue components of the scene. If all three of these color images were converged at one point through the use of an optical system, and the human eye placed at this point, it would see the scene in its original colors since it is receiving the three primary color components of this scene simultaneously.

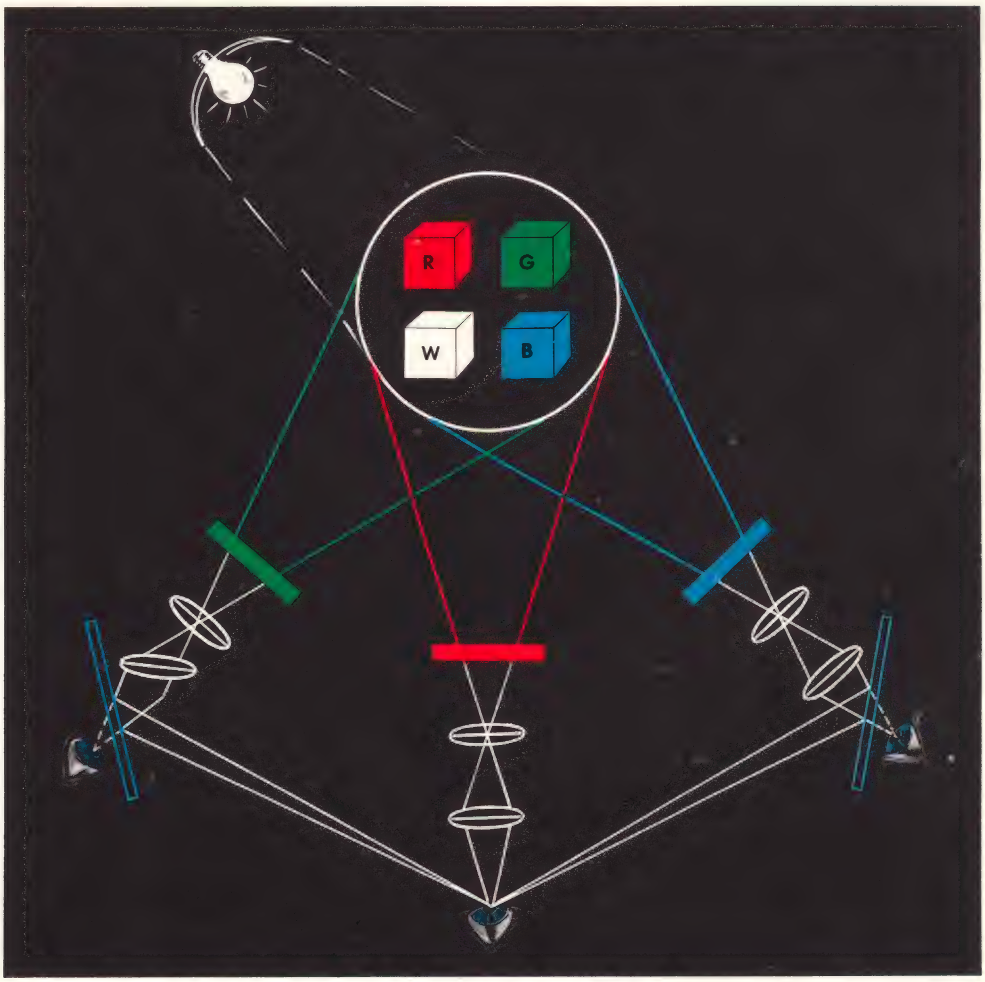


Figure 1-19. Reproducing Original Scene

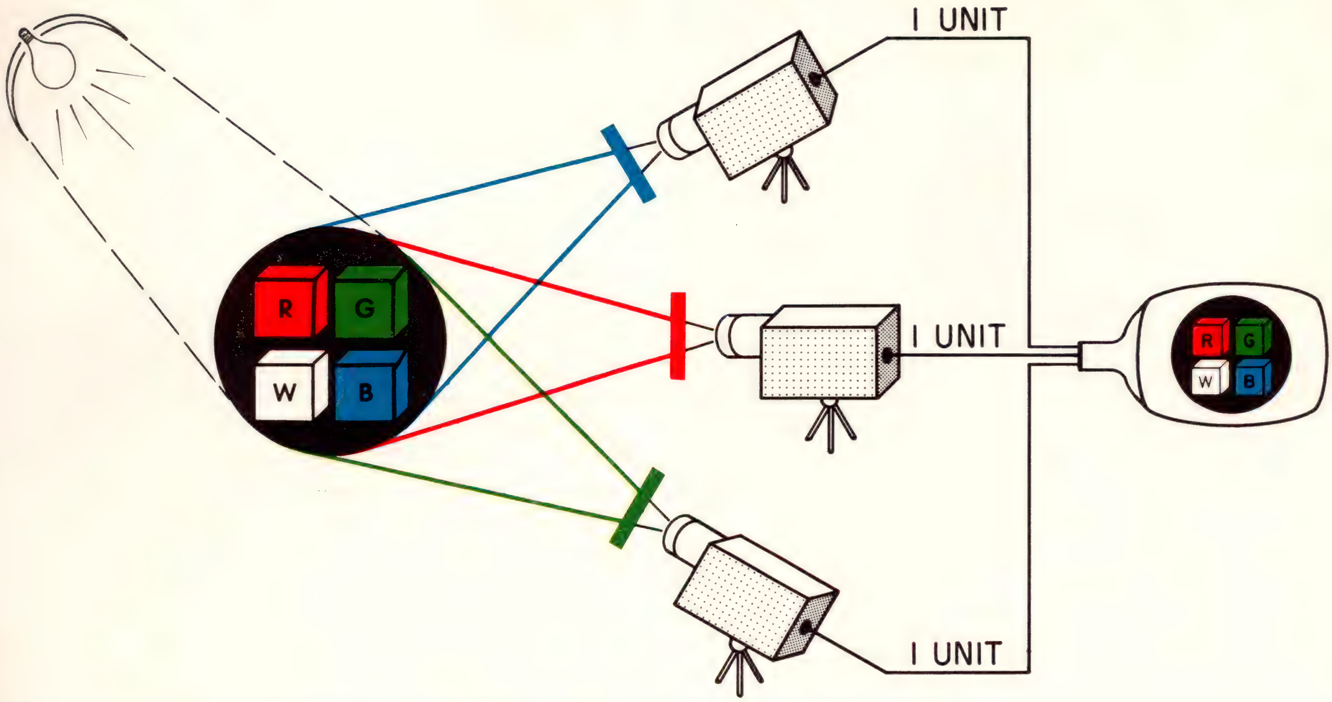


Figure 1-20. Televising Scene in Primary Color Components

Now, if we were to take the original scene, illuminate it with white light, and put a black and white television camera behind each of the filters, as seen in Figure 1-20, each of these cameras would see a different color component of the scene. The camera behind the green filter would see only the green components of the scene, since the filter would only let green light through. The red camera would see only the red components of the scene, and the blue camera would only see the blue information in the scene.

If we were to view this scene on a color tube, we would want to put 100% of each of the color signals on the color tube. This would produce a color image of each object on the screen. Since the white object causes output from all three of the cameras when it is being scanned, each of the guns in the color tube would be creating an image of the white object simultaneously on the screen. These superimposed color images are the primary colors, so we will see the "W" object as white. Because of the brightness response of the eye to various colors, we would see green as 59% as bright as white, red as 30% as bright, and blue as 11% as bright—the same as if we viewed the original scene directly.

Figure 1-21 shows the three cameras connected to a black and white picture tube. If only the camera behind the green filter were attached to a black and white picture tube, only the green and white objects would be seen on the screen, as a black and white scene. Both objects would be equally bright since the camera output would be seeing only the green primary components of the scene.

If only the camera behind the red filter were connected to the picture tube, only the red and white objects would be seen on the screen. The camera behind the blue filter would only produce the blue and white objects on the black and white picture tube screen. In both these latter cases, the two objects visible on the screen would be the same brightness.

If the outputs of all three cameras were connected together and applied to the black and white television tube, we would see the original scene but in terms of brightness only. All the objects would appear to be as equal white.

Under these conditions, we would want to adjust the outputs of the three cameras so that each would put out a voltage that was equal to the sensitivity of the eye for that particular color. If the white object in the scene produced a brightness response in the eye of 100%, green would produce a brightness response of 59%, red 30% and blue 11%. So, in order to produce a black and white picture that would have the proper gray scale reproduction of the color scene, the signal going to the black and white picture tube would be adjusted to give us 59% of the green camera output, 30% of the red output and 11% of the blue output.

A regular black and white television camera has

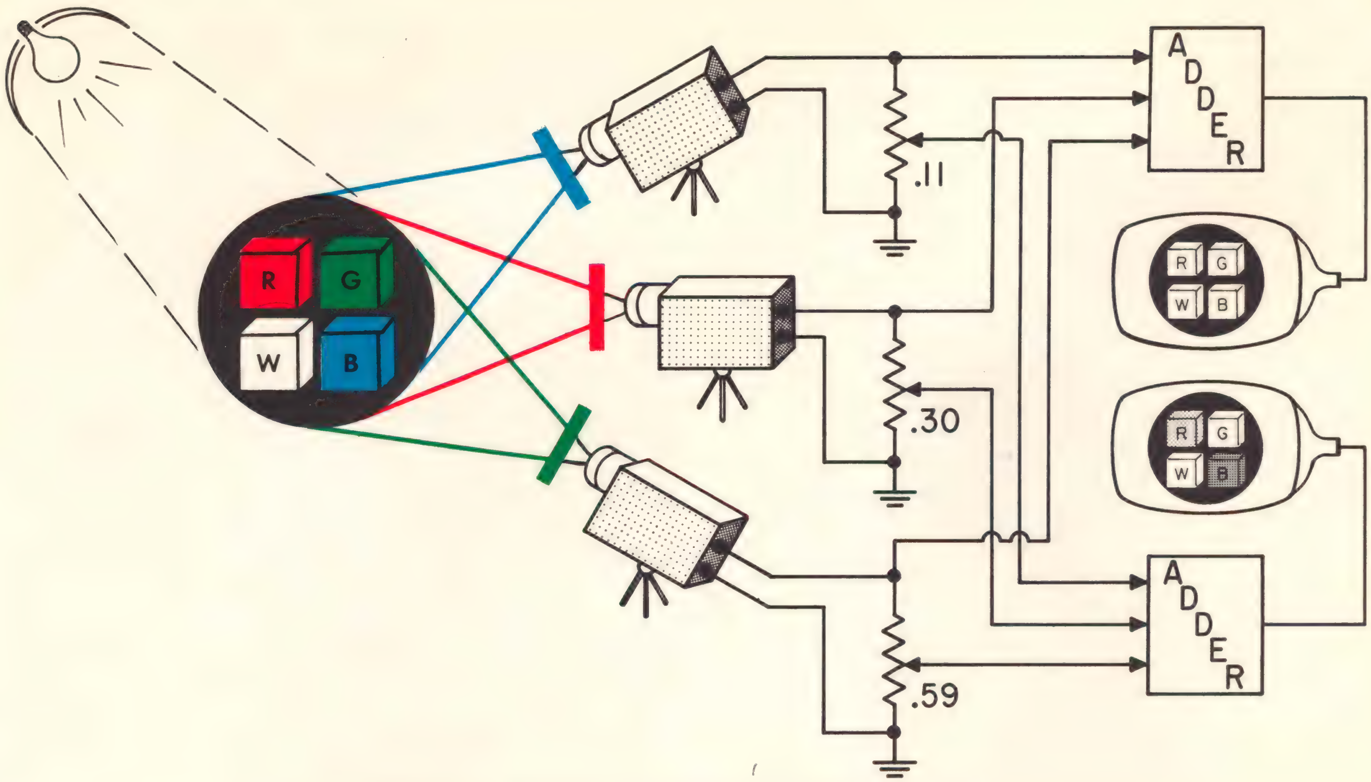


Figure 1-21. Television Color Scene In Terms of Brightness

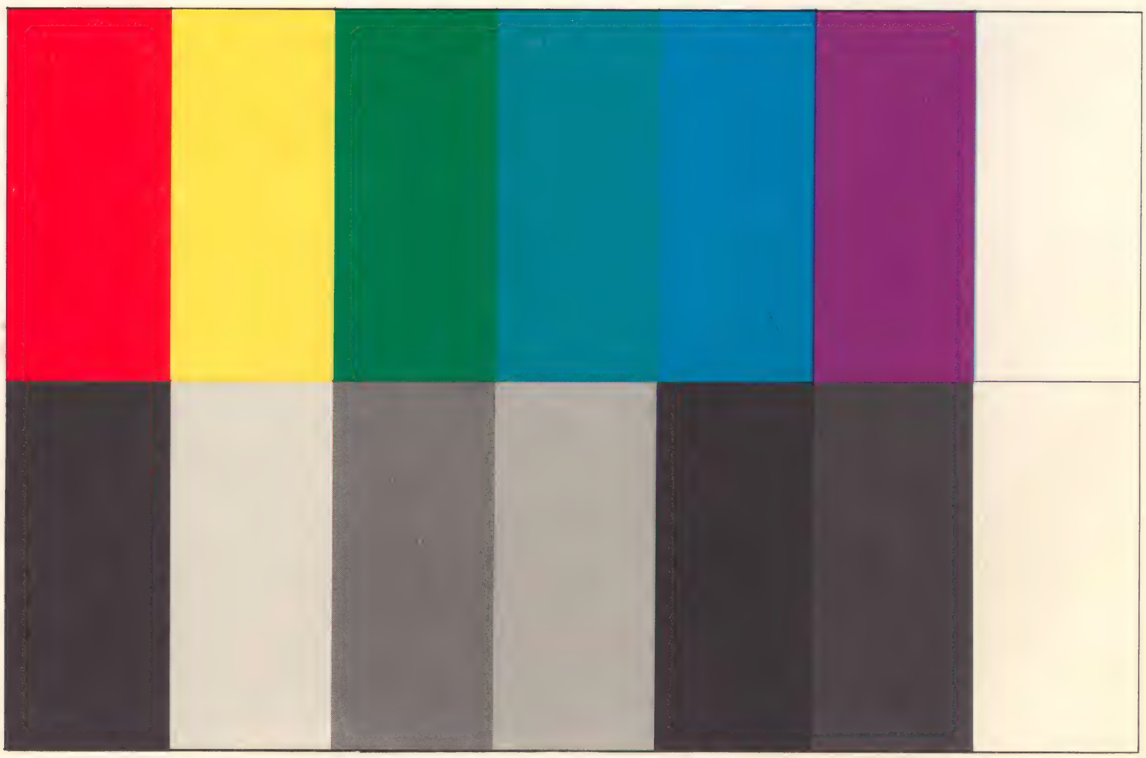


Figure 1-22. Gray Scale

its sensitivity to color adjusted so that it peaks in the green region, the same as a normal eye. Black and white photographic film also has a similar brightness response to colors so it will render different colors in the spectrum a different shade of gray. Figure 1-22 shows the three primary and three complimentary colors used in our color system and their associated brightness reponse.

2 / Compatible Color TV System

Let us now proceed to see how we can apply the facts we know about light and human vision to a color television system.

Figure 2-1 shows a chromaticity diagram which is a chart of all the visible colors that can be seen by the human eye. The large horseshoe curve with the numbers plotted along its edge represents the colors appearing in a spectrum of sun light, giving the wavelength of these colors in millimicrons. The color triangle within the horseshoe curve is the total range of colors that we are able to reproduce in our color televison system using the standard primaries of red, green and blue. The range of colors we are able to reproduce is greater than color printing or color photography.

Let us examine how the colors blend into each other as we go around the edge of the triangle. Starting with blue in the lower left corner, we proceed counterclockwise around the triangle and see that we go from blue to magenta, which is blue-red, on up to red at the side of the triangle, on around through orange-yellow and to green in the top corner of the triangle. Then back down to blue with the shades of cyan or aqua in between. All of the colors along the edge of this triangle would be defined as 100% saturated colors. As we proceed from the edge toward the center of the triangle, the colors become less saturated until at a point near the center, we have white, which is completely desaturated colors.

This diagram was devised by engineers so that any color could be identified in terms of an X and Y plot on a graph. A shade of green, for example, having the values of X = .3 and Y = .6 could be reproduced exactly at some distant point by simply communicating these X and Y values.

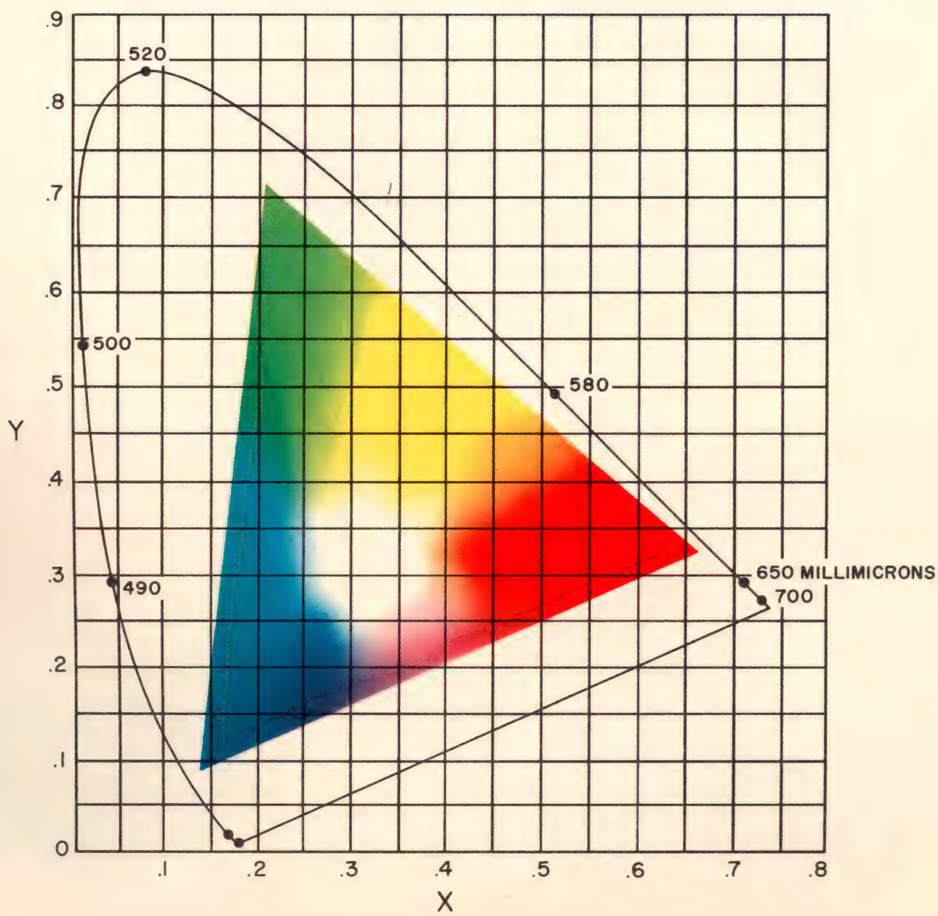


Figure 2-1. Chromacity Diagram

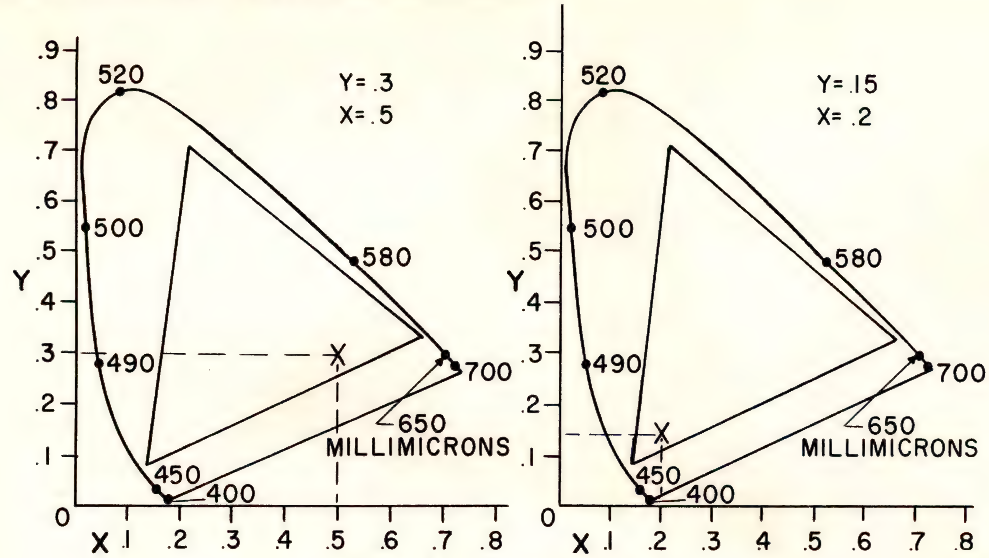


Figure 2-2. Identifying Colors

To identify any other color on the graph, it is only necessary to project a line as a perpendicular from the color to the X and Y axes and read the values directly. See Figure 2-2.

Examining, briefly, the mechanics of plotting points on a graph, refer to Figure 2-3. Ordinary graphs like those shown in business reports and statistical illustrations are of the type that is illustrated in the shaded area of Figure 2-3:1. The point where the vertical axis (Y) and the horizontal axis (X) meet, we consider being the zero point. Going vertically upward from this zero point is the + or positive direction on the Y axis; going to the right, horizontally from the zero point along the X axis, is the + or positive direction. Any point in this shaded quadrant is expressed as + quantities of X and Y direction. For example, Point A, Figure 2-3:1, is +.3Y and +.2X, as shown by the dotted lines. All the other points on this graph can also be identified as some + value of X and Y axes.

Figure 2-3:1 shows how we can identify points in other quadrants of the graphs. Point B is above the zero point along the Y axis at the +.3 mark. However, it is to the left of the zero point on the X axis, so it will now be a minus quantity along this axis. The identification for Point B is +.3Y and −.4X.

Point C is in the quadrant where both X and Y values are minus, so its identification is −.4Y and −.2X. Point D would be identified as −.1Y and +.5X.

Figure 2-3:2 shows how we can assign a numerical value of .4 to a point, and by merely changing the combination of + and − values of X and Y axes, have this point appear in all quadrants of the graph.

Instead of calling these two axes X and Y, we can call them by other identifications.

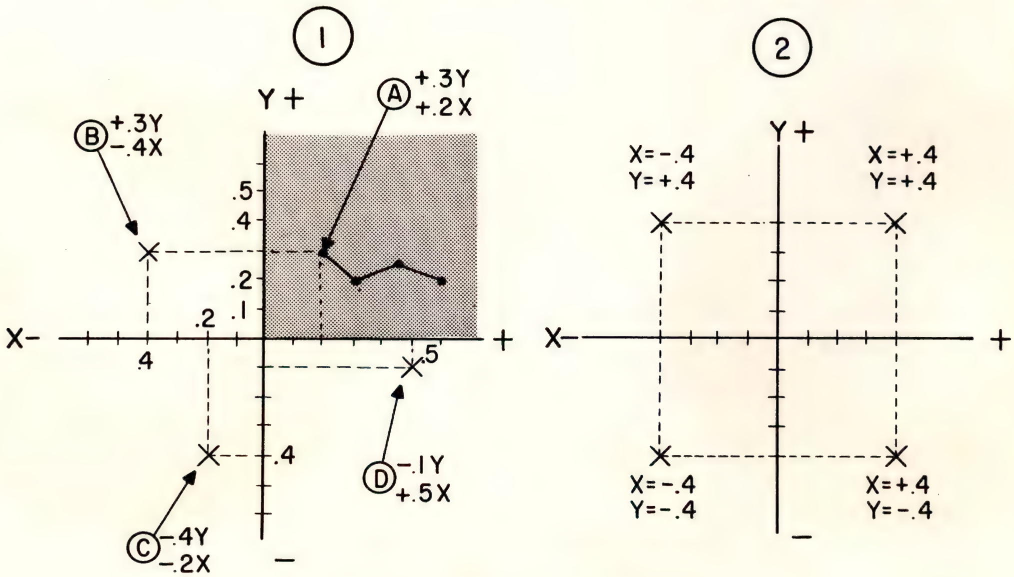


Figure 2-3. Mechanics of A Graph

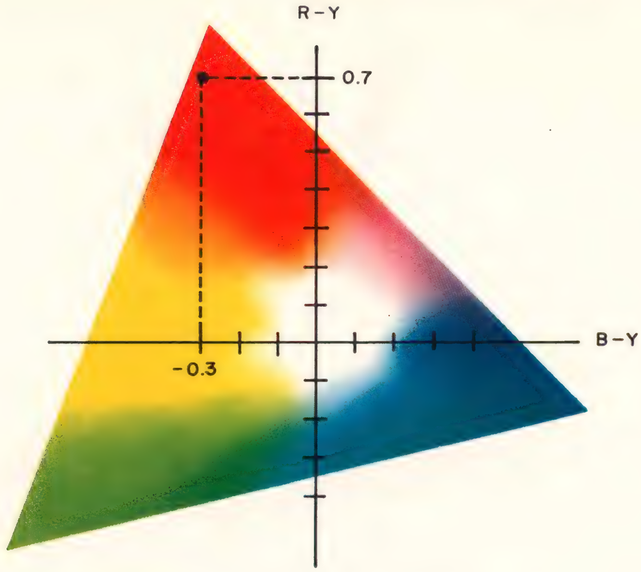


Figure 2-4. Color Triangle with R-Y and B-Y Axies

Referring to the color triangle, Figure 2-4, we have repositioned it to put blue on the right. We can arbitrarily draw two intersecting axes on the triangle and label one the B-Y axis and the other R-Y axis. It is possible now to see that it is not necessary to always identify a color on the X and Y plots of this chart, but we can also identify any color in certain percentages of the B-Y axis and the R-Y axis (Figure 2-4). A certain color red, for example, may be defined as +.7 (R-Y) and −.3 (B-Y).

Let us cut a circle out of the center of this color triangle (Fig. 2-1) and re-shape it so that white is exactly in the center.

Figure 2-5 shows such a circle, which we will refer to as a color wheel. Here we have the same relationships of color as we did on the chromaticity diagram; going from blue to cyan, to green to yellow, red, magenta and back to blue. But instead of the X and Y coordinates that we had on the chromaticity chart, let us now identify these colors in terms of the R-Y axis and the B-Y axis. A magenta color can be identified in terms of a certain percentage of R-Y direction and a certain percentage of the B-Y direction.

We can also identify a certain color of green in these terms. Figure 2-6 shows such a description. This green can be identified in so many units of minus direction B-Y axis, and so many units of a minus direction of the R-Y axis. When we have these percentages of the two axes, we can at any time reconstruct or redefine that particular color of green.

In terms of R-Y axis and B-Y axis, we can define or locate any color in the color wheel, merely in terms of minus or plus quantities of these two axes.

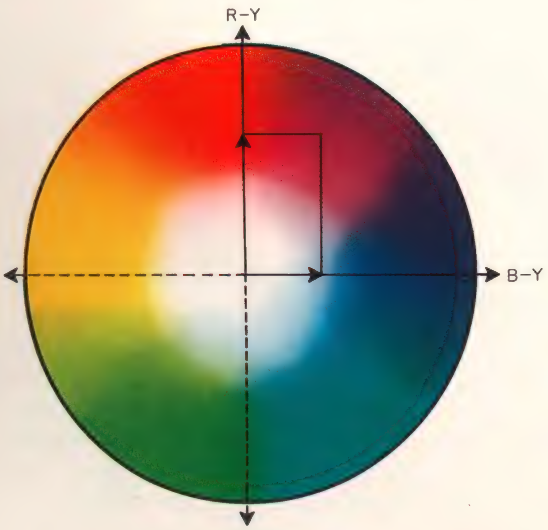


Figure 2-5. Identifying Magenta From R-Y and B-Y Information

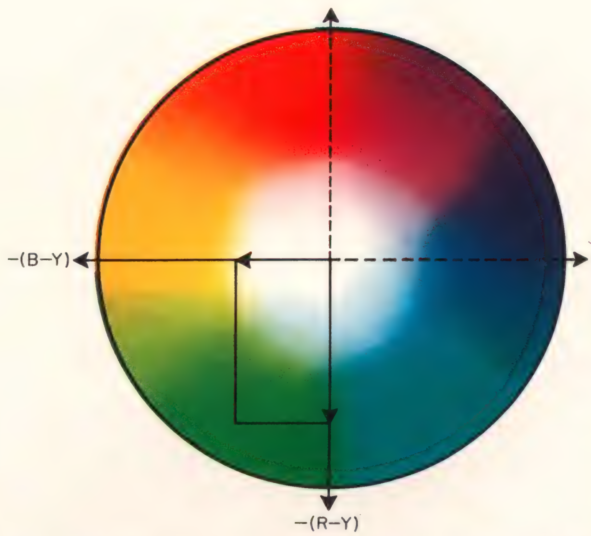


Figure 2-6. Identifying Green in Terms of R-Y and B-Y

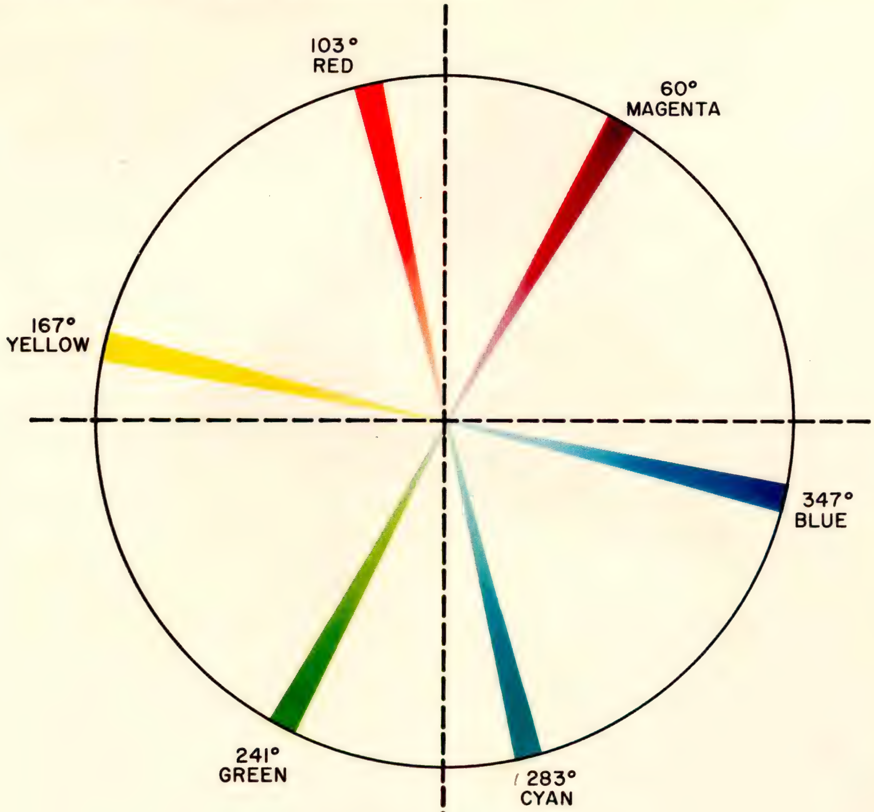


Figure 2-7. Electrical Phase of Colors

Now that we have these colors represented along the circumference of a circle, we can also identify each color as so many degrees of a circle. Figure 2-7 shows the color wheel with only the primary and complimentary colors and the degrees of rotation that they appear.

Colors can now be identified two ways; in degrees of rotation around the circumference of a circle and in terms of + and/or − values of two axes at right angles to each other (quadrature). This arrangement makes it very convenient for us to use a vector rotating through 360° to identify a hue by its direction, and have its length indicate the amount of saturation.

Before we examine the method of making a sinewave phase represent a certain color, let us review briefly some basic sinewave and vector principles.

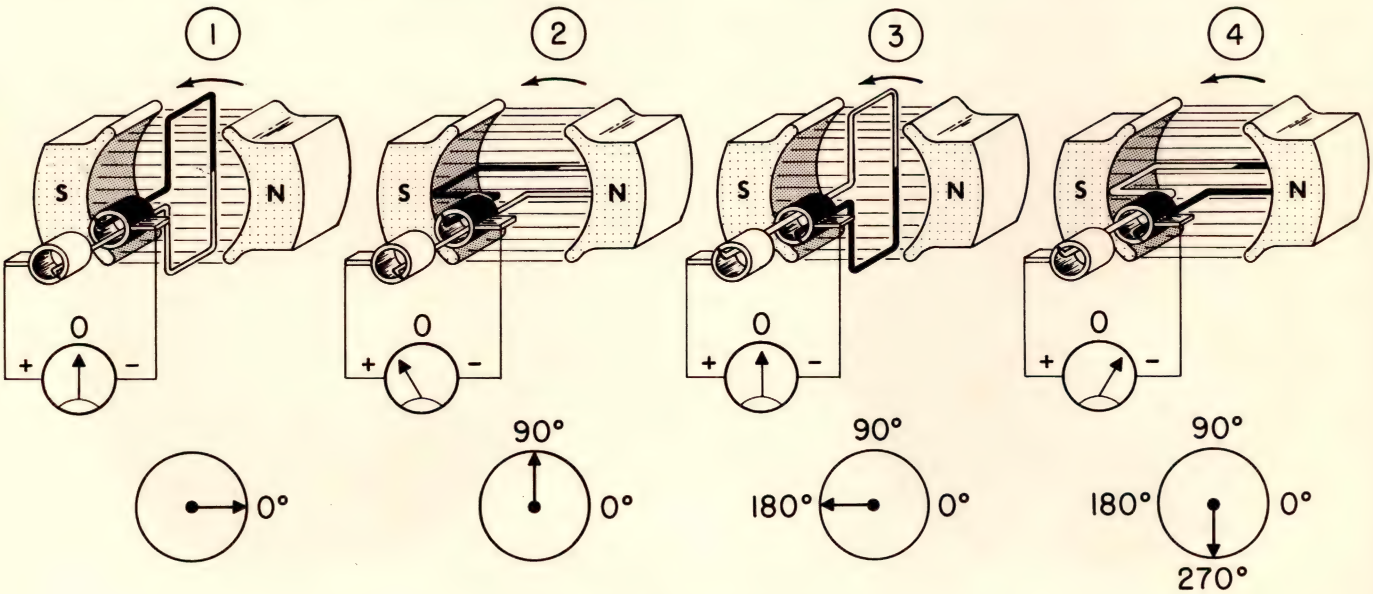


Figure 2-8. Simple Alternator

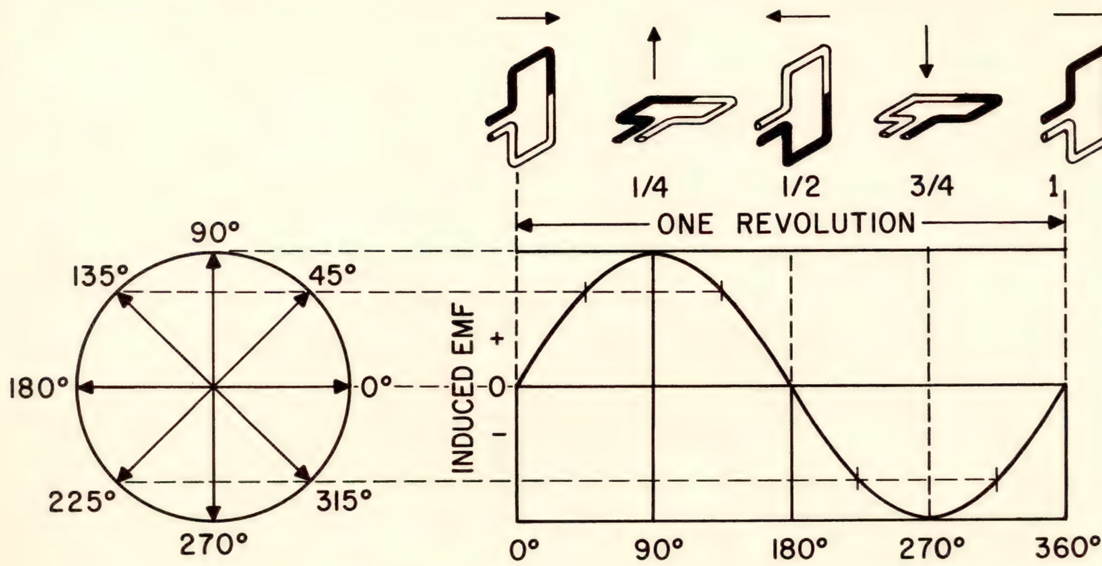


Figure 2-9. Generator of Sine Wave

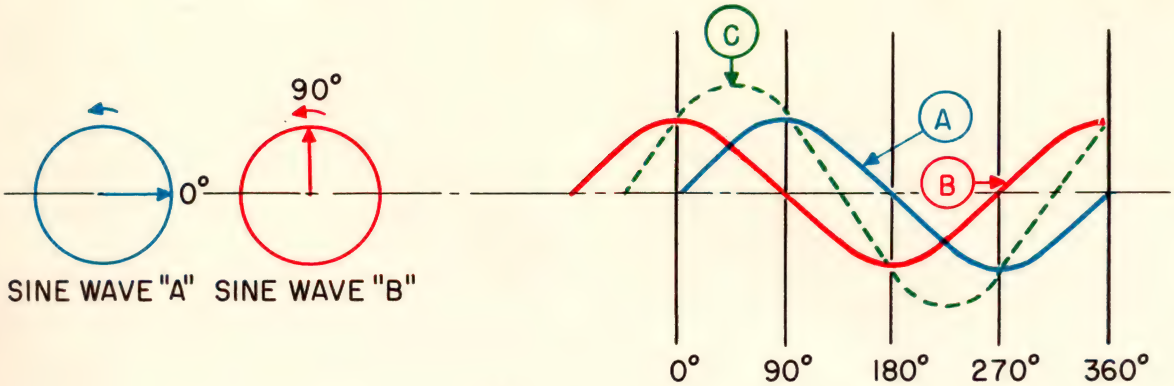


Figure 2-10. Sine Wave Displaced By 90°

Sinewaves and Vectors

Figure 2-8 shows a loop of wire rotating in a magnetic field. Beneath each illustration is a vector (arrow), representing the position (phase) of the loop in the magnetic field. When the loop rotates through the position in Figure 2-8:1, the black coil side is moving toward the south pole and the white side is moving toward the north pole. Because the conductor is moving parallel to the direction of the magnetic field, no flux lines are cut and the induced voltage is zero. The meter which is connected across the output will read zero volts. The conductor is connected to slip rings which rotate with the conductor. Stationary carbon brushes contact the slip rings and conduct the voltage to the meter.

After the conductor has rotated 90° from its initial position (Figure 2-8:2) and is passing through the position shown, the black coil side is moving downward and the white upward. Both sides are cutting a maximum number of flux lines and the induced voltage (indicated by meter) is at a positive maximum.

As the loop passes through the position shown in Figure 2-8:3, the coil sides are again cutting no flux lines and the generated voltage is zero.

As the loop passes through the position shown in Figure 2-8:4 the coil sides are cutting a maximum number of flux lines and the generated voltage is at a negative maximum. The next 90° revolution of the loop completes the 360° revolution and the generated voltage is zero.

Summarizing the above—as the loop makes one revolution of 360°, the induced voltage passes from zero to a positive maximum, to zero, to the negative maximum, and back to zero. If the speed of rotation is constant, the output voltage will be a sinewave as shown in Figure 2-9.

The circle and sinewave illustration, Figure 2-9, illustrates how a vector can be made to represent the phase and amplitude of a sinewave at any instant of time. The vector on the circle pointing toward the

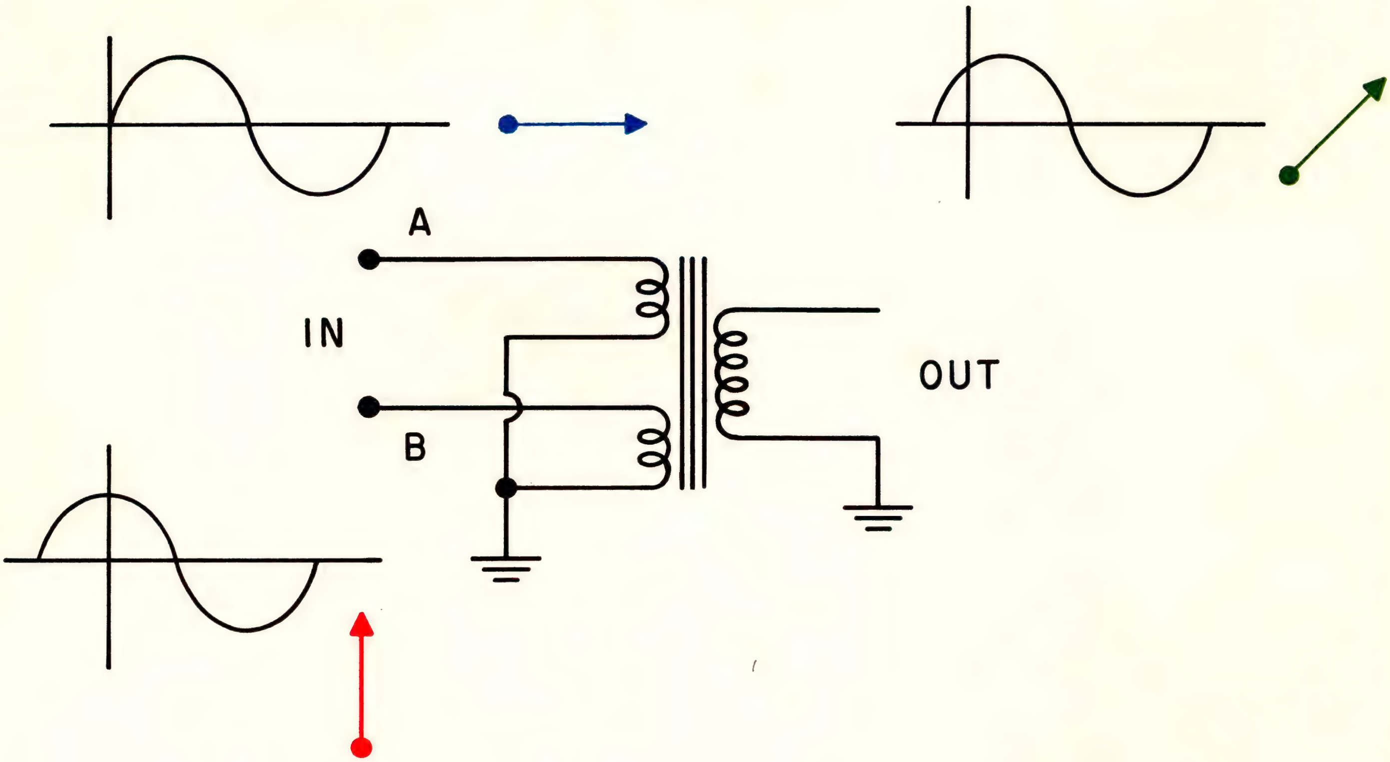


Figure 2-11. Adder Circuit

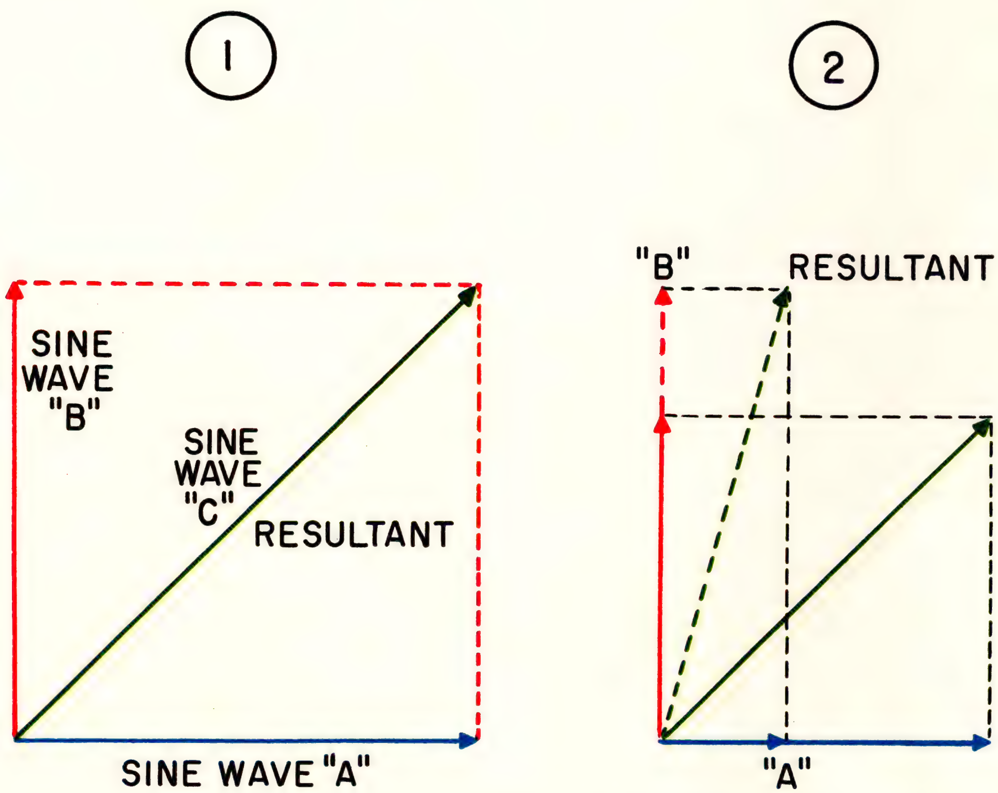


Figure 2-12. Magnitude of Vectors

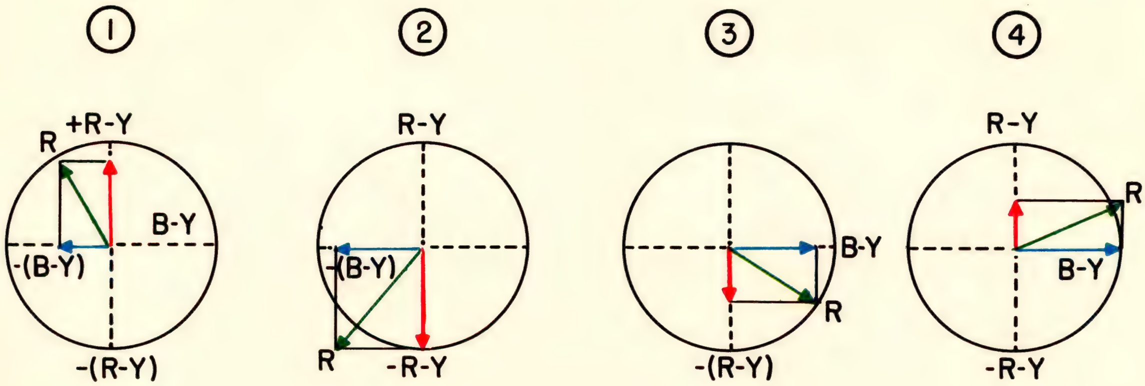


Figure 2-13. Addition of Vectors

zero degree point, corresponds to the zero degree point on the graph of the sinewave. As the vector proceeds counterclockwise to the 45° position, and then on to the 90° position and finally on back to the zero degree position, the representative sinewave phase and amplitude is indicated in the graph.

Let us now take two of these sinewave generators, rotate them at exactly the same speed (frequency) but have one of them leading (ahead of) the other by 90° in its rotation phase (position). Since we can illustrate this relationship with vectors, let us draw it as in Figure 2-10.

The armatures that are producing these sinewave voltages are turning at some speed that would make them difficult to observe, which means that the vectors are turning at the same rate. So, to be able to observe them and determine their action, we figuratively stop them at the same instant on every cycle. We will use the blue vector as our standard and stop it at every cycle so that it is in the 0° position. This will then describe the blue sinewave shown in Figure 2-10.

The red vector represents the generator that is leading (ahead of) the blue vector by 90°. This means that it is 90° further along in its rotation, in a counterclockwise direction, than the blue vector. The output voltage described by this vector is shown by the red sinewave. If we inject these two sinewaves into an appropriate device, we can add them together and produce a resultant sinewave that will have a different phase than either of the originals. This resultant is shown as the green sinewave in Figure 2-10.

A circuit that would give us an addition of the two original sinewaves is shown in Figure 2-11, along with vectors indicating the two input phases and the resultant phase. This shows that we can explain the relationship between two or more sinewaves by showing the direction (or phase angle) of their vectors.

Figure 2-12 shows how we can combine vectors to get a resultant phase indication without the necessity of drawing sinewaves. By drawing vectors "A" and "B," Figure 2-12:1, as two sides of a parallelogram, the diagonal becomes the resultant, or the phase angle of the resultant sinewave.

There is one more characteristic of a vector that we are interested in. This is its relative length. While the direction of the vector indicates its phase, the length represents the magnitude or amount of sinewave amplitude. If the length of vectors "A" and "B," Figure 2-12:1, each represent 1 volt, the length of vector "C" will equal 1.4 volts. Figure 2-12:2 shows how different length vectors "A" and "B" will change the phase and amplitude of resultant "C," within the limits of the parallelogram they form.

Figure 2-13 illustrates the addition of different combinations of vectors that are 90° displaced, to produce resultants in all quadrants of a circle. Relating this to the color wheel (Figures 2-5, 6, 7), we have kept our two 90° displaced vectors on the same axes as represented by the R-Y and B-Y directions in the color wheel, while causing the resultant to appear at various places around the circle.

Figure 2-13:1, the blue vector represents a minus direction on the B-Y axis, and the red vector represents a plus direction of the R-Y axis. Figure 2-13:2 shows both vectors as having minus directions of the two axes. Figures 2-13:3 and 2-13:4 show the two remaining combinations.

The position of the resultant vector around the circle represents a particular hue, and its length (magnitude) relates to the saturation of that hue.

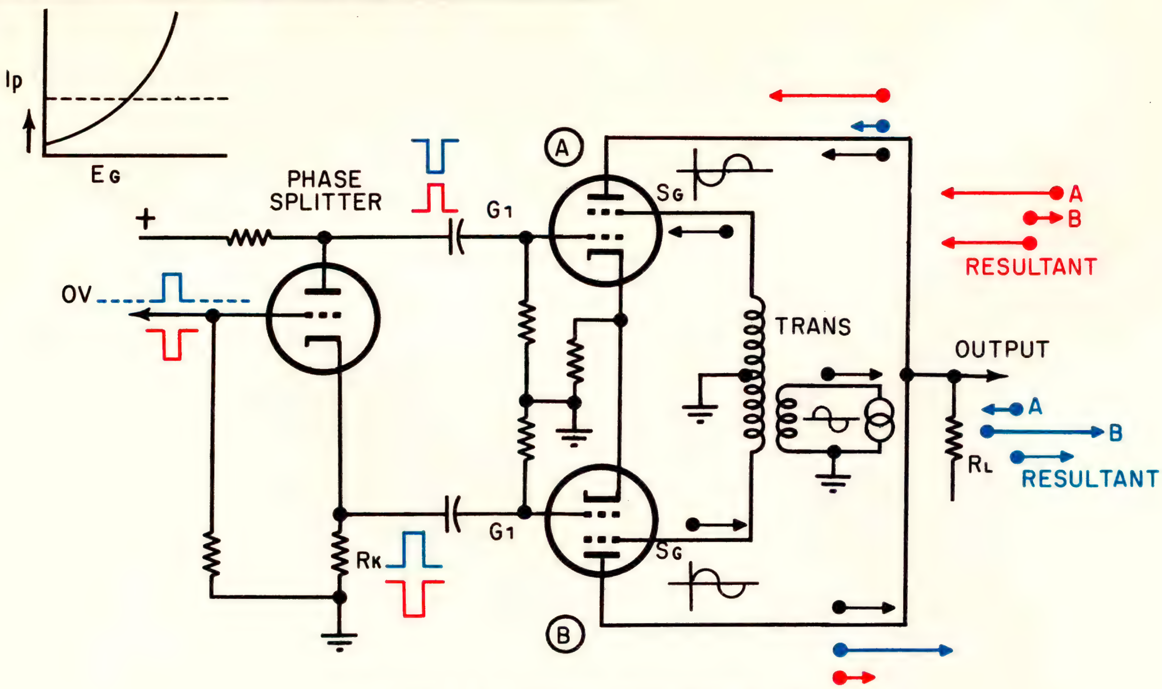


Figure 2-14. Balanced Modulator No. 1

Up to this point, we have found that a vector describes the phase and magnitude of a sinewave and that two vectors in quadrature (90° displaced) will produce a resultant vector that can appear at any point in the 360° of rotation. We now have a method by which we can use the phase of a sinewave to define a color as shown on the color wheel. In practice, two balanced modulators are used to give us the necessary quadrature sinewave voltages to obtain the resultant we desire.

Formation of the Color Signal

Figure 2-14 shows a balanced modulator circuit in which we can change the amplitude and polarity of the output sinewave by changing the characteristics of the input video signal.

The theory of operation of a balanced modulator is quite simple. We show here two tubes, tube A and tube B, with their plates tied together to a common load resistor. The screen grids of the two tubes are connected to opposite ends of the tapped secondary of the exitation transformer. The primary of the transformer is connected to a source of RF sinewave voltage which induces an equal and opposite polarity voltage on each of the screen grids. The two balanced modulator tubes are biased so that they operate on the portion of the grid voltage, plate current curve shown.

Since the screen grids are connected to opposite ends of the exitation transformer, with the center tap grounded, the phase of the sinewave voltage appearing at these two screen grids will be of opposite polarity. We will indicate this condition by the opposite pointing vectors by the tube sockets. With no input signals to the control grids, the signals appearing in the plate circuit will completely cancel out and the resultant RF voltage appearing across the plate load resistor will be zero. The two black vectors (arrows) drawn near the output of each plate circuit, indicate the conditions that we find in the plate circuit for a balanced condition with no signal input. The direction the arrow points indicates the phase of the signal in that plate circuit, and the length of the vector indicates its amplitude. Since the lengths are equal and the direction of the vectors are opposite, the signals appearing across the plate load resistor will cancel out.

At the input circuit of the balanced modulator, the grid of tube "A" is connected to the plate of the phase splitter, and the grid of tube "B" is connected to the cathode of the phase splitter. With this arrangement, any signal that is applied to the grid of the phase splitter will appear in the same phase on the grid of the balanced modulator tube "B", and 180° out of phase, or inverted, on the grid of balanced modulator tube "A".

Let us now follow a video signal through this balanced modulator system and see what happens. A positive going pulse (or signal) is fed into the grid of the phase splitter. Across cathode resistor R, we will see the same positive signal. This positive pulse is injected into the control grid of tube "B". In the plate circuit of the phase splitter, we have a 180° reversal of the signal and we find that we have a negative pulse on the grid of tube "A".

The negative signal on the grid of tube "A" drives its grid negative and increases the bias on tube "A"

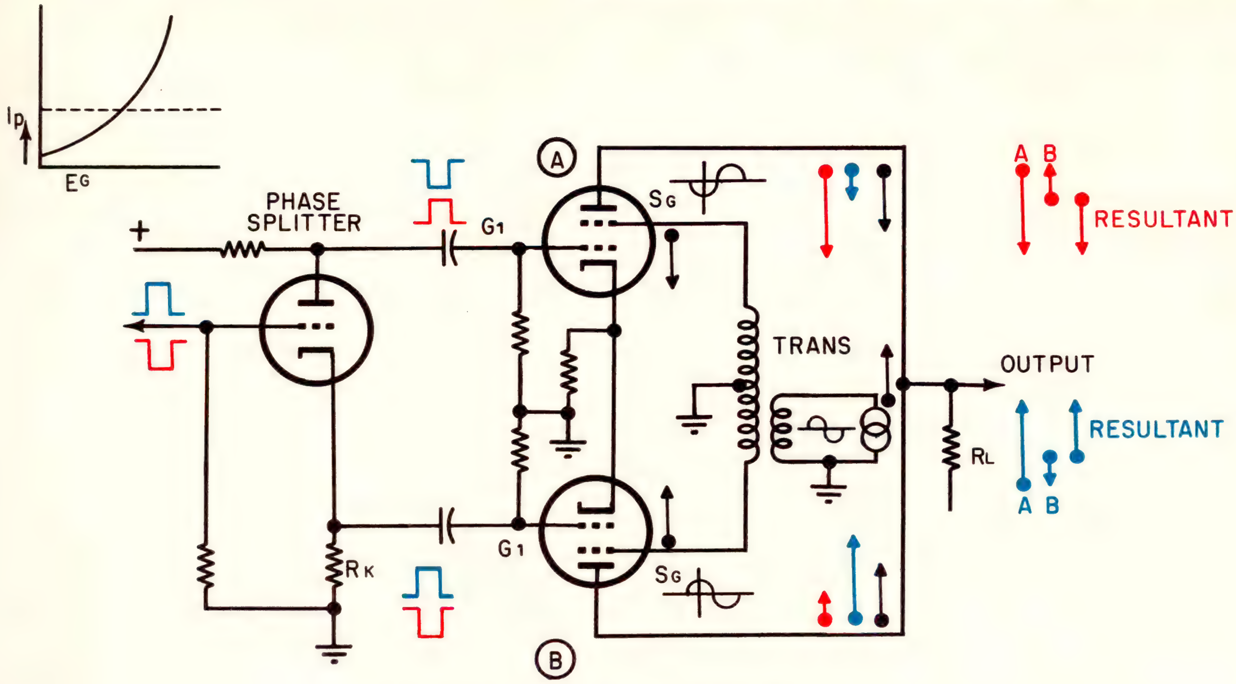


Figure 2-15. Balanced Modulator No. 2

for the time the signal is present. This will result in less signal voltage in the plate circuit of tube "A" as indicated by the blue colored vector. The phase of this vector is still the same as it was under balanced conditions but its amplitude is now one-half of that amount.

Tube "B" now has a positive signal on its grid, and this will have the effect of reducing the bias of tube "B". This will be reflected in the plate circuit as an increase in oscillator signal, as indicated by the blue vector on its plate. This vector now indicates that the phase of the signal in the plate of tube "B" is the same as it was under the balanced condition, but will now be twice the amplitude. Across the output resistor RL, we will find signal "A" going in one direction at half the amplitude of the balanced condition, and signal "B" going in the opposite direction at twice the amplitude of the balanced condition, causing vector "A" to be subtracted from vector "B" and giving us the resultant vector as shown. While we have no output from the balanced modulator with zero signal into the system, we now have an output which is the same phase as seen in the plate of tube "B" when we have a positive signal into the grid of the phase splitter.

Let us now put a negative signal into the grid of the phase splitter and follow this through the balanced modulator. This one is colored red so that we can trace it through. The same negative pulse appears on the grid of the balanced modulator tube "B". This negative pulse then biases tube "B" so there will be less oscillator signal in the plate circuit as there was in the original balanced condition. The phase of the signal will be the same but its amplitude will be reduced, as represented by the red vector.

The same negative pulse going into the phase splitter now becomes a positive pulse on the grid of tube "A". This increases the signal through tube "A" which allows more of the oscillator energy to appear in tube "A's" plate circuit. The phase will be the same as when the tube was balanced, but the amplitude will be greater as represented now by the red vector in the plate circuit of tube "A". Across plate load resistor RL, the signals of both of the red vectors will appear, the smaller vector "B" will subtract from larger vector "A" and the resultant output signal will be of the amplitude indicated, in the same phase as normally appearing in tube "A". Here we can see that the character of an input signal to a balanced modulator can control the polarity and output amplitude of the modulator.

By changing the phase of the oscillator signal into a balanced modulator, it is possible to get outputs of different phases as compared to the illustration just discussed. Figure 2-15 shows the outputs of a balanced modulator with the same two video signal conditions in, but with the oscillator leading the phase of the original oscillator by 90°.

By combining the outputs of these two balanced modulators and varying this amplitude and polarity separately, we can produce a sinewave signal whose phase will fall anywhere within the 360° of our color circle. Figure 2-16 illustrates this. The outputs of balanced modulator #1 and balanced modulator #2

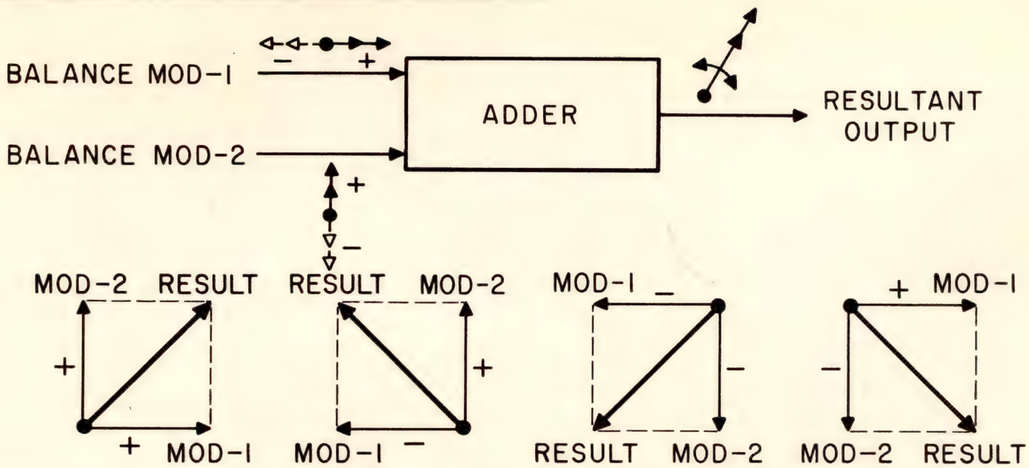


Figure 2-16. Chrominance Adder With

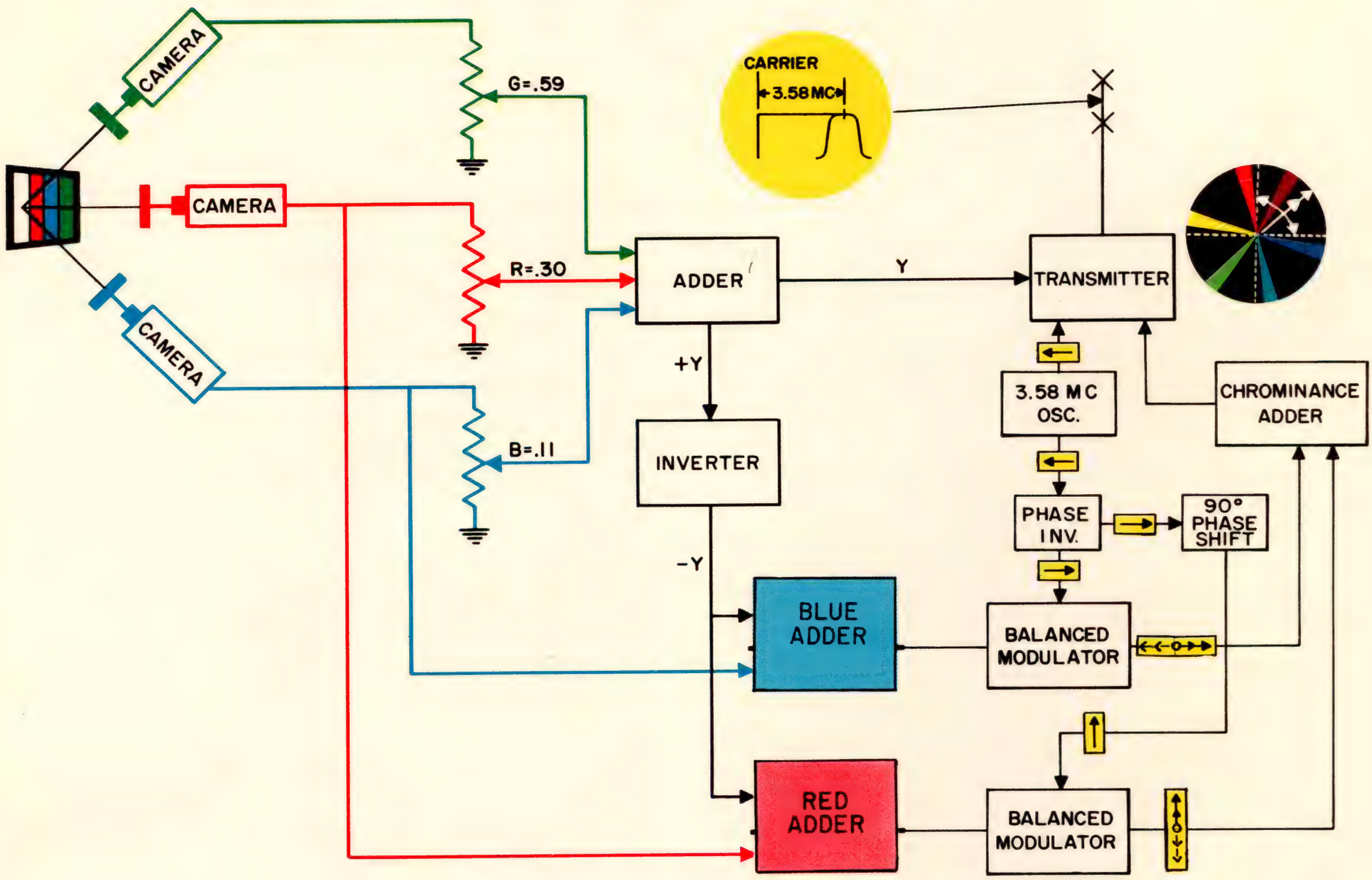


Figure 2-17. Compatible Color TV Transmission System

are combined in an adder to give us a resultant output. The four illustrations indicate again how the phase of the resultant can be made to appear in the four quadrants of our color wheel.

Producing A Compatible Color Signal

Let us take what we have learned about the characteristics of the eye, the characteristics of light, and the fact that we can define colors by the phase of the sinewave, and apply this to a compatible color television system.

Figure 2-17 shows the block diagram of such a system.

In the upper left-hand corner, we have our three color sensitive cameras. One sensitive to green, one to red and the other to blue. To make this system compatible with existing black and white television receivers, it is necessary that we take the outputs of these cameras, and combine them in a manner that will give the proper gray scale reproduction in a

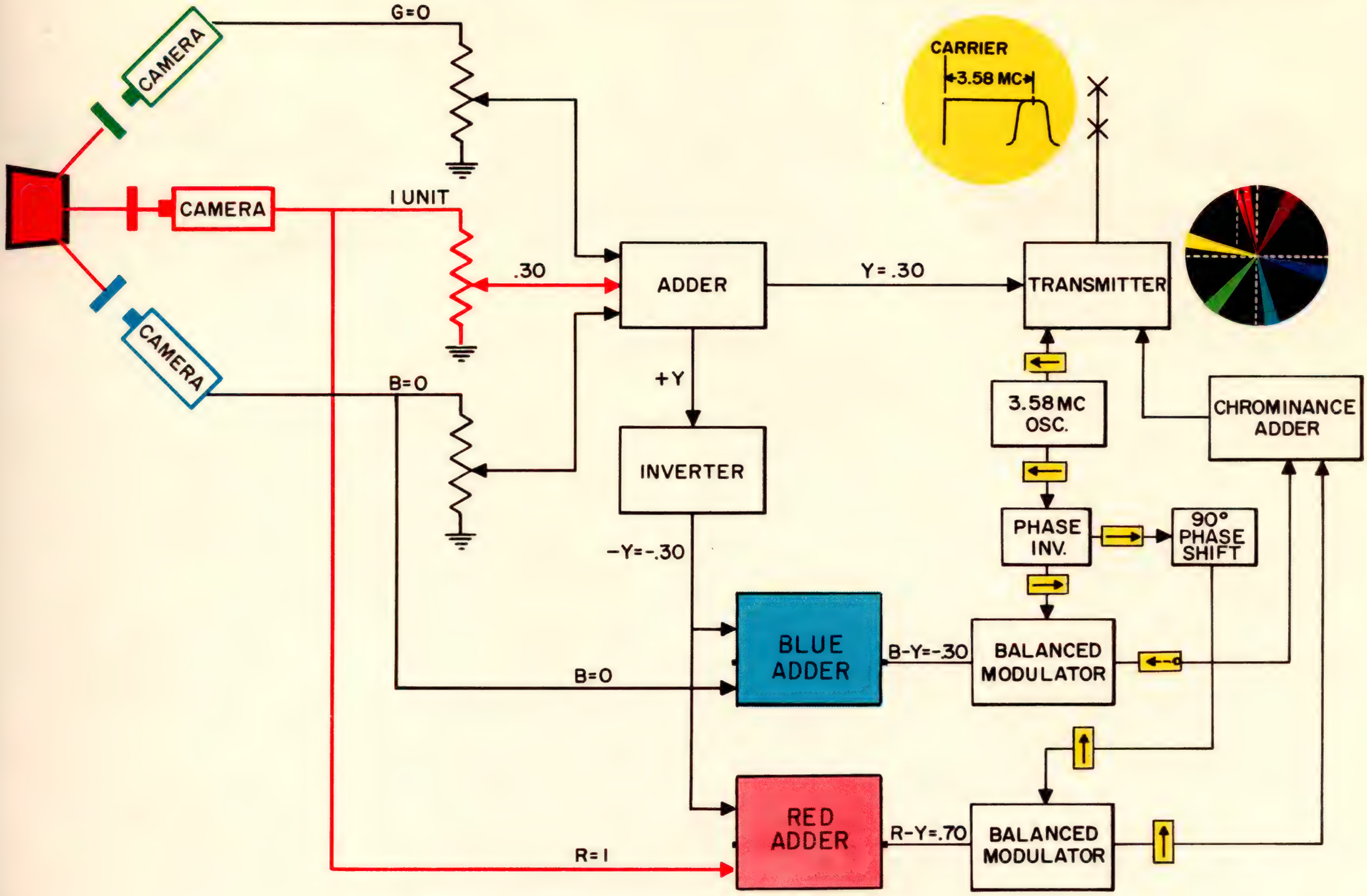


Figure 2-18. Signals in Transmitter for Red Bar

black and white television receiver. As you recall, the eye sees different brightness levels in the different colors of a scene, so it is necessary for us to provide these different brigtness levels. To do this, we take 59% of the total output of the green camera, 30% of the total output of the red camera, and 11% of the total output of the blue camera. These are fed into an adder and the resultant output comprises the black and white signal which then modulates the transmitter.

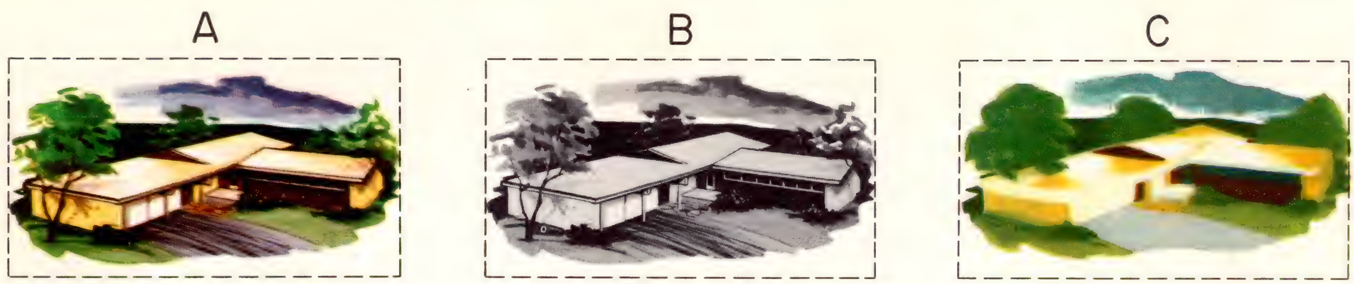
It is only necessary to transmit these relative brightness levels because of compatibility with black and white receivers. If it were not for this consideration, we could transmit the total camera outputs to the color receiver. The brightness response characteristic of the eye would then impart to our senses the appearance of 59% brightness of the green image, as compared to white, 30% for red and 11% for blue.

The total outputs of the red and blue cameras are fed into adders, where they are combined with an inverted black and white signal. Since the black and white signal is sent separately, we wish to subtract it from our color signal at this point and have the color signal contain only hue and saturation information information.

The output of the red and blue adders are each fed into separate balanced modulators, which are excited by a RF oscillator maintaining a 90° phase relationship between the exciting voltages. The blue balanced modulator is excited by an oscillator of 0° phase and the red balanced modulator is excited by an oscillator signal of 90° phase. The outputs of the two balanced modulators are then fed into the chrominance adder, which combines these two signals into a resultant signal which is then injected into the transmitter where it modulates the video carrier.

Let us take some actual conditions and put some values into the system.

Figure 2-18 shows the signals in the transmitter for a red bar transmission. With all three cameras focused on a red scene, the green camera and the blue camera will have no output, since there is only red color in the scene. The red camera, however, will have one unit output which is fed directly to the red adder, and through the voltage divider to pick off the 30% brightness level for our compatible black and white transmission. Since the green and blue signals are zero, they will contribute nothing to the brightness adder output, our black and white or brightness signal will be a 30% value. This 30% brigtness signal is inverted and is applied to the blue



Full Color Picture — Brightness Information — Color Information

Figure 2-19. Components of Color Scene

and red adders as a –30% signal.

In the red adder, we have a +100% signal from the red camera and a –30% signal from the black and white inverter; these two signals will add algebraically, and the resultant output will be a +70% signal (100–30=70). Since the brightness (black and white) signal has been identified as the "Y" signal, the output of the red adder then becomes a R-Y signal since it is the red information minus the Y, or brightness information.

The inputs to the blue adder are the –30% black and white signal, and the zero signal from the blue camera, since there is no blue camera output on a red scene. Adding these two algebraically gives us a –30% signal out of the blue adder which is the B-Y signal. [0 + (–.30) = –.30.] The –30% signal out of the blue adder then modulates the blue balanced modulator which gives an output as shown by the dotted vector in the 180° position.

The red balanced modulator is modulated by the +70% [R-Y] signal and its output is indicated by the solid vector in the 90° position.

The outputs from both balanced modulators are sent to the chrominance adder where they form the resultant signal as shown and modulate the video carrier. This color signal will cause a sideband of the video carrier at the same frequency used to excite the balanced modulators. This frequency was selected to be 3.58 mc. Since it appears at the high frequency end of the video response band, it will result in low visibility information in the black and white transmission.

The black and white signal modulates the transmitter as a full bandwith signal since all fine detail is transmitted in the black and white signal. The subcarrier region of the transmitted envelope is of reduced bandwith since there is no fine detail transmitted in the color signal.

Figure 2-19 shows how this would appear if we could receive each component separately. The original scene would be represented by the full color, high definition picture "A". In the "Y" channel, there would be the brightness information including all the fine detail, which means that this would be transmitted at full bandwidth, or 4·2 mc. This is represented in Figure 2-19 as "B". The color channels would transmit the information shown as "C" and would be at reduced bandwith since the eye does not see fine detail in color. This signal is the hue and saturation information.

We now have the black and white signal, and the color signal modulating the transmitter, but there is still a third signal which we have not yet discussed. This is the color sync signal.

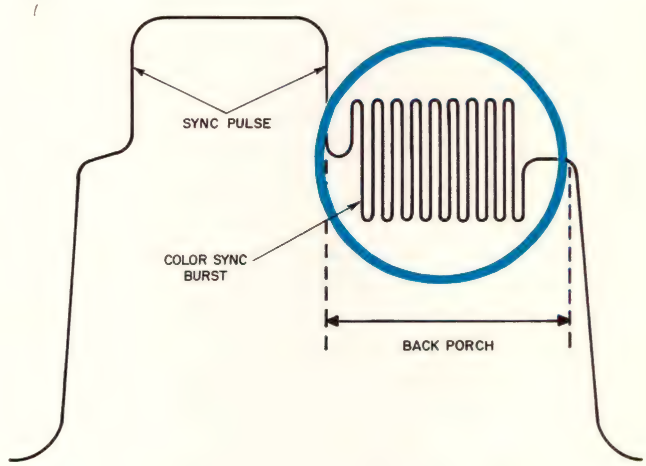


Figure 2-20. Horizontal Blanking Pedistal

Figure 2-20 shows how the color synchronizing signal is transmitted. On the back porch of each horizontal sync pulse is placed a minimum of 8 cycles of reference 3.58 mc signal. This color sync signal is generated by the same oscillator that generates the exciting voltages for the balanced modulators, so consequently always maintains an exact phase relationship to these balanced modulator voltages. This burst of color sync information usually occurs only during a color transmission.

The video signal leaving the transmitter contains:

1. Black and white, or brightness information (called the "Y" signal) including regular sync information. This is the high resolution signal with a bandwidth of 4.2 mc.

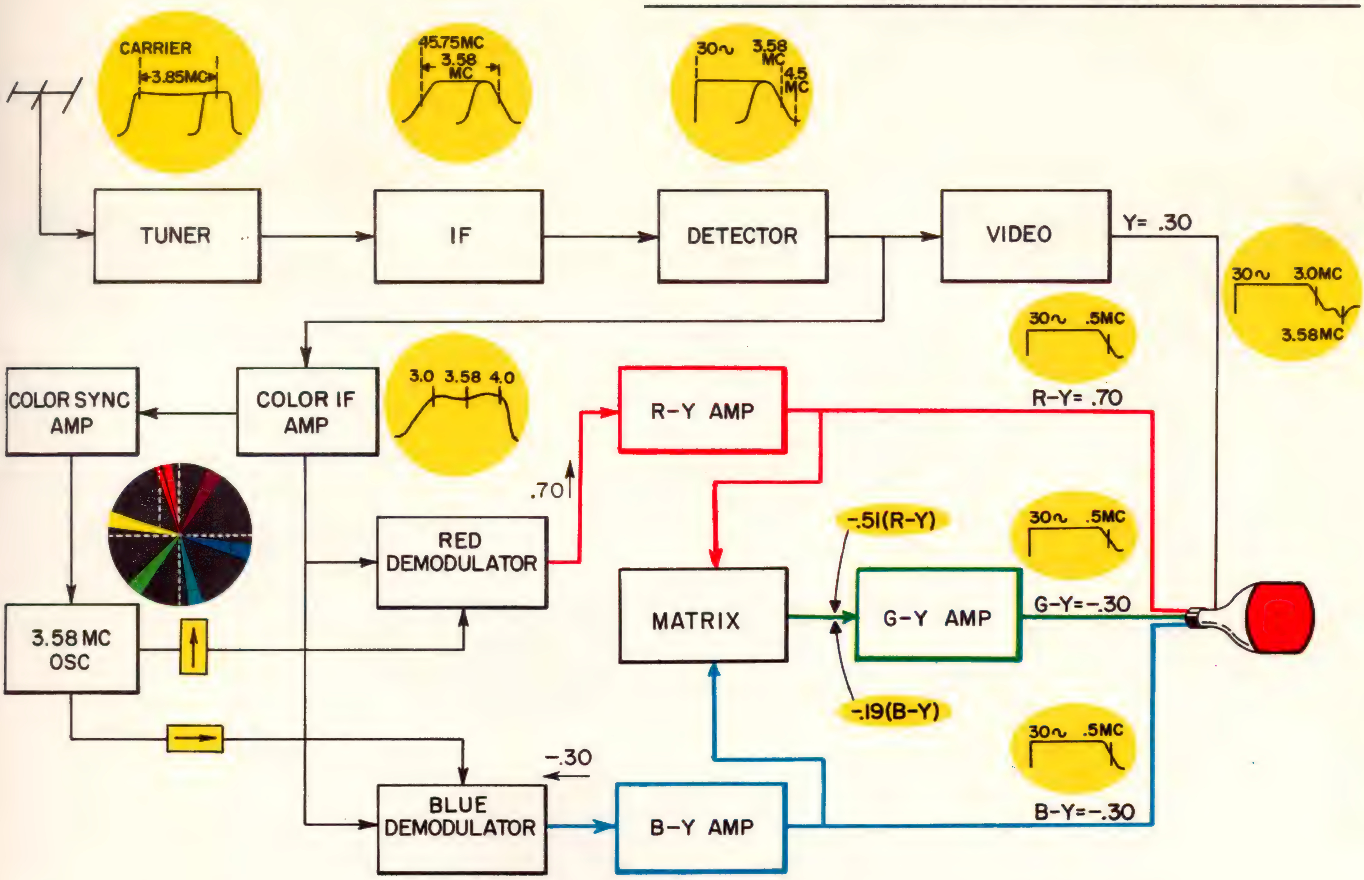


Figure 2-21. Signals in Receiver For Red Bar

2. The 3.58 mc color subcarrier which contains hue and saturation information (called the chrominance or color signal). This is a reduced bandwidth signal of .5 mc.

3. The color synchronizing signal, which gives us a reference phase with which to compare the color signal in the receiver.

Signals in Color Receivers

Let us follow this color transmission through a color receiver for a red bar. In Figure 2-21, we have the block diagram of our color receiver, showing the tuner, IF and detector, with the bandwidth response curves expected in each portion.

The tuner bandwidth must be wide enough to pass the total transmited RF signal. This includes the 4.2 mc wide video carrier (including color subcarrier) and the sound carrier, which is 4.5 mc higher in frequency than the video carrier.

A local oscillator in the tuner hetrodynes with the amplified RF signal and produces an intermediate frequency (IF) which is amplified at a fixed frequency. The IF amplifier has a bandwidth of 3.58 mc which places the video IF carrier at 50% on one side of the curve and the color subcarrier at 50% on the other. The IF beat frequency produced by the sound carrier appears 4.5 mc lower in frequency than the video IF carrier and is sharply attenuated to prevent interference in the picture. This does not affect the sound information since a separate sound IF amplifier is provided.

After amplification, the IF signal is detected and we recover the complete video signal (including color subcarrier). This will be a wide band signal with frequencies from 30 cycles to over 4 mc. This signal takes two paths (Figure 2-21).

The first path through the video amplifier, amplifies the black and white portions of the signal, and at the cathodes of the three guns of our color picture tube, we recover a 30% brightness signal that contains all of our fine detail and brightness information. Since this is applied to all three cathodes, all three guns have a 30% "ON" signal. Let us leave this signal here for a moment, and go back and follow the other paths that the detected video signal takes.

Color IF

Let us first consider the COLOR IF amplifier, which is tuned to a center frequency of 3.58 mc with a total bandwidth of one mc. This amplifier then is sensitive to only the color subcarrier frequencies, and will exclude all the brightness information. The output of the color IF amplifier is the amplified color signal which contains hue and saturation information. This is applied to the grids of the two demodulators.

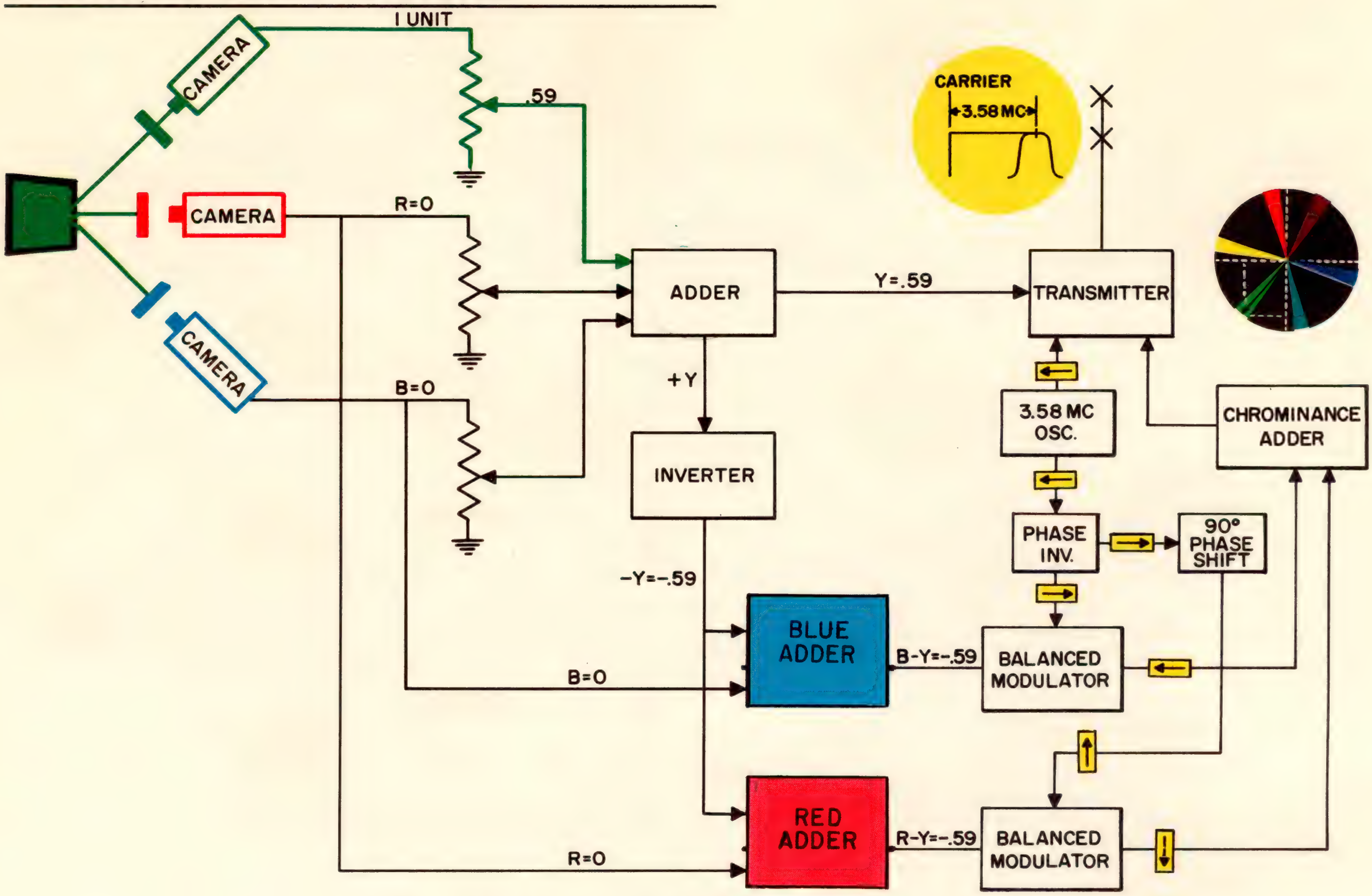


Figure 2-22. Signals in Transmitter For Green Bar

Part of the amplified signal from the color IF amplifier is channeled to the color sync amplifier, which amplifies only during horizontal retrace time, which is the time that color sync is present. The color sync burst is amplified and sent into a phase detector which compares its phase and frequency with the local crystal oscillator, and provides correction voltages to the crystal oscillator to maintain phase and frequency stability. The 3.58 mc oscillator has two outputs; the 90° phase output excites the red demodulator and the 0° phase output excites the blue demodulator.

The demodulators will have outputs determined by the phase of the color signal being injected into them. The red demodulator will have maximum output in the positive direction when the color signal is in the same phase as the exciting voltage, and will have maximum negative output when the color signal is 180° out of phase with the exciting voltage. The blue demodulator will have maximum positive output when the incoming color signal is in the same phase as its exciting voltage, and will have maximum negative voltage output when the incoming color signal is 180° out of phase with the exciting voltage.

The output from the red demodulator is fed into the R-Y amplifier and appears in the output as a positive 70% signal. This is connected to the red grid of the color tube. The output of the blue demodulator is fed into the B-Y amplifier and the output appears as a –30% signal. This is applied to the grid of the blue gun in the color tube.

When we were talking about the color wheel, in a previous figure, we determined that any color in the color wheel could be expressed and defined in terms of B-Y and R-Y directions. In order to recover the G-Y signal at the receiver, it is necessary that we take certain amounts of the R-Y and B-Y signals to accomplish this. The amount needed is –51% [R-Y] and –19% [B-Y]. This equals the G-Y signal. By putting this combination into the G-Y amplifier, we come out with a –30% signal in this case. This is applied to the grid of the green gun of the color tube.

Examining the picture tube, we have these signals present. On the cathodes of all three guns we have a positive 30% brightness signal, which is, as far as the picture tube is concerned, 30% "ON" signal. On the grid of the red gun, we have a 70% "ON" signal which means the red gun is turned on 100%. On the green gun, we have a –30% signal on the grid and a positive 30% signal on the cathode, which cancels and results in no signal on the green gun. On the blue grid, we have a –30% signal, and on

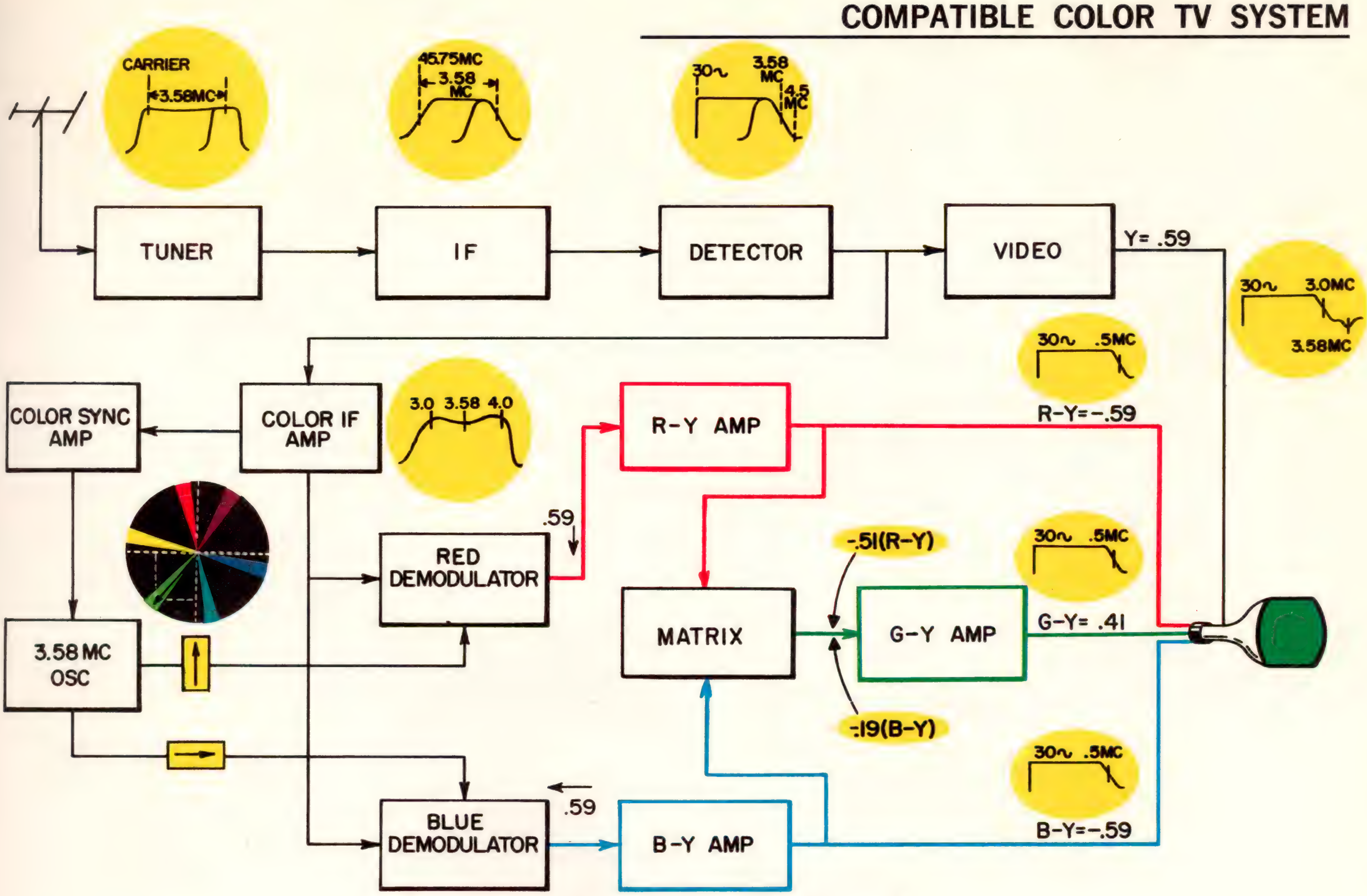


Figure 2-23. Signals in Receiver For Green Bar

the cathode we have a positive 30% signal; these two cancel out giving the blue gun a zero signal. We have the red gun "ON" 100% and the green and blue guns turned off, giving only a red raster which reproduces the original scene.

Figure 2-22 shows the signals transmitted for a green bar. With this condition, only the green camera will have output and 59% of this signal is fed into the black and white signal adder. Since green gives the eye the sensation of being only 59% as bright as white, this is the brightness level then that will be transmitted in our black and white channel.

The red and blue cameras have no output, so there will be no percentage of these signals to include in the brightness signal. Since the red and blue camera outputs are zero, this zero voltage is added to the inverted black and white signal, and both of these color adders will have a −59% output signal. The outputs of both balanced modulators will have a negative signal output, which when added together in the chrominance adder, will modulate the transmitter with the phase shown. The transmitter then, for the green bar, will be transmitting the black and white signal with a brightness level of 59%, the color subcarrier with a phase of approximately 241°, and the synchronizing information.

In the color receiver, Figure 2-23, the output of the detector contains all of the video modulating information which is separated into its various paths. At the output of the video amplifier, we find the black and white signal to represent a 59% brightness level, and this is applied to the cathodes of all three guns.

The color IF amplifier, amplifies the color subcarrier and because of its pass band response, excludes all of the brightness information and sends this signal to the grid of both demodulators.

The color sync amplifier, amplifies only the sync information and controls the phase and frequency of the local 3.58 mc oscillator.

The outputs of both the red and blue demodulators will be a signal representing negative voltage, and will appear as negative 59% signal in the outputs of both the R-Y amplifier and the B-Y amplifier. These signals are applied to the grid of the red and blue guns.

Again, by taking the proper percentages of the R-Y and B-Y signals, we develop the G-Y signal which is a positive 41% signal. This is applied to the grid of the green gun and combined with the 59% positive signal on the cathode, turns on the green gun 100%. Since the red and blue guns each have a −59% signal on their grids and a +59% on their cathodes, these signals cancel out and the red and blue guns have zero signal and are turned

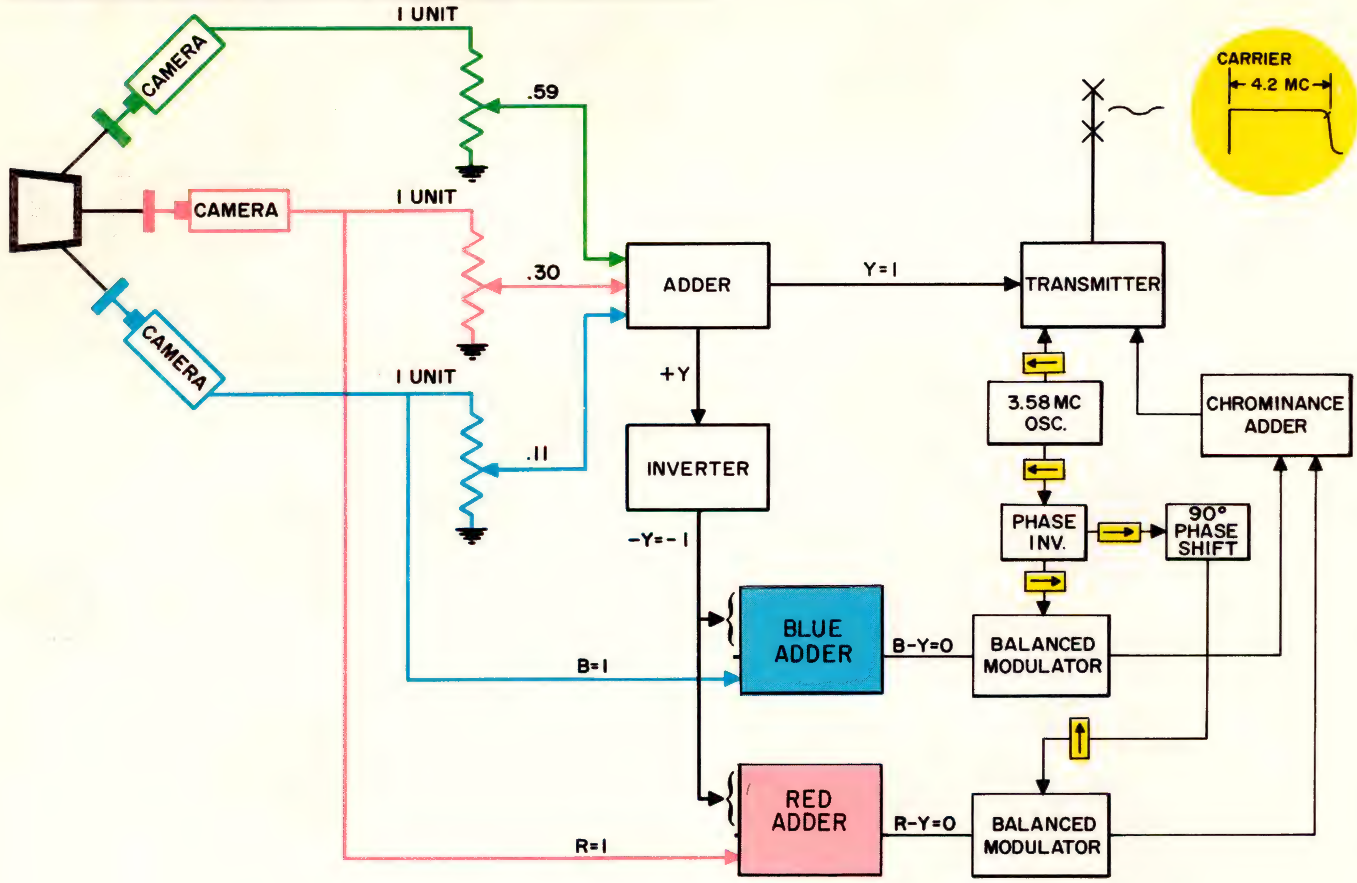


Figure 2-24. Signals In Transmitter For White Bar

off. The green gun is turned on 100%, producing a green raster which reproduces the original scene.

Figure 2-24 shows the transmission of a white scene. Since, as we learned, white will reflect all colors of light, each of our three cameras will have maximum, or one unit of output. The outputs of all three cameras are divided down in the proportion of human eye brightness response to the individual colors, and combine in the adder to produce our black and white, or brightness signal. Again, these proportions are 59% green, 30% red and 11% blue; which totaled will equal 100%.

The total output of the red camera is fed into the red adder and the total output of the blue camera is fed into the blue adder. Since all three cameras were putting out one unit and we divided down certain percentages to indicate the brightness level of the scene in terms of the three colors, the black and white, or brightness signal comes out as one unit ($.59G+.30R+.11B=1.0$). This is the maximum brightness that will appear in the transmission. This black and white signal is inverted and becomes a -1 unit, and is inserted into the red and blue adders. In the blue adder, we have a $+1$ signal out of the blue camera, and a -1 signal out of the black and white inverter which gives us a resultant of zero.

So the output of the blue adder will be zero. The color signal into the red adder is a $+1$ unit and the inverted black and white signal is a -1 unit; these will cancel out and the output from the red adder will be zero.

Since there is no signal input to either of the balanced modulators, there will be no oscillator signal out. On a transmission that contains only black and white information, with no color, there will be no subcarrier or color signal formed.

Figure 2-25 shows how this signal will be received in a color receiver. The tuner accepts the total signal, both sound and video, where it is converted to an IF frequency and amplified with the proper bandwidth. From the IF, the signal goes into the detector, where the video information is detected out of the IF signal. The bandpass response of the detector is from 30 cycles to 4.0 mc, dropping off sharply at 4.5 mc, which is the sound beat note frequency. From the detector, the video signal is amplified in the video amplifier and emerges as a signal of one unit amplitude. This is applied to the three cathodes of the color tube.

Since there is no color information in this transmission (only black and white information), there will be no signals through the color circuits so the outputs of the three color amplifiers will be zero.

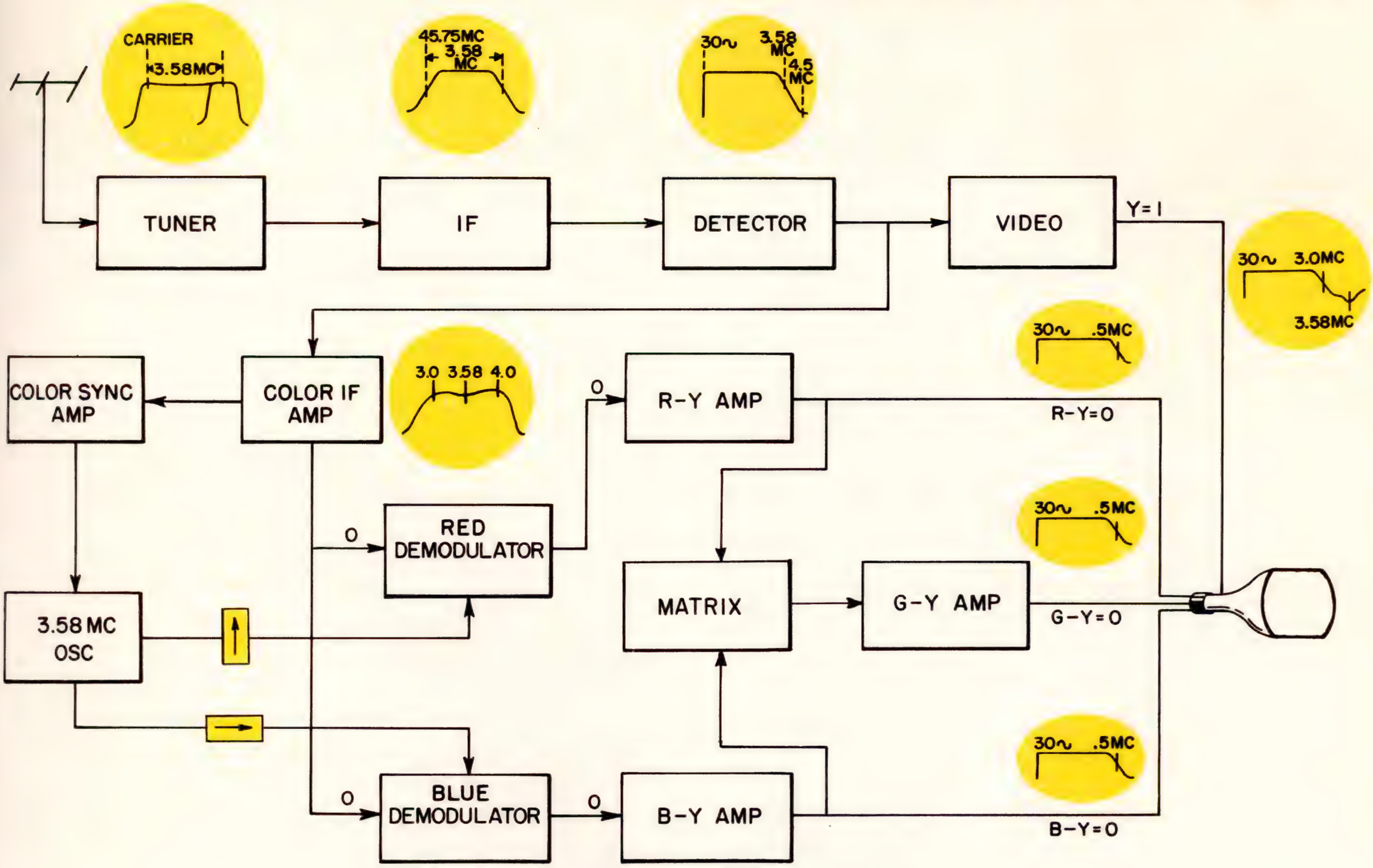


Figure 2-25. Signals in Receiver For White Bar

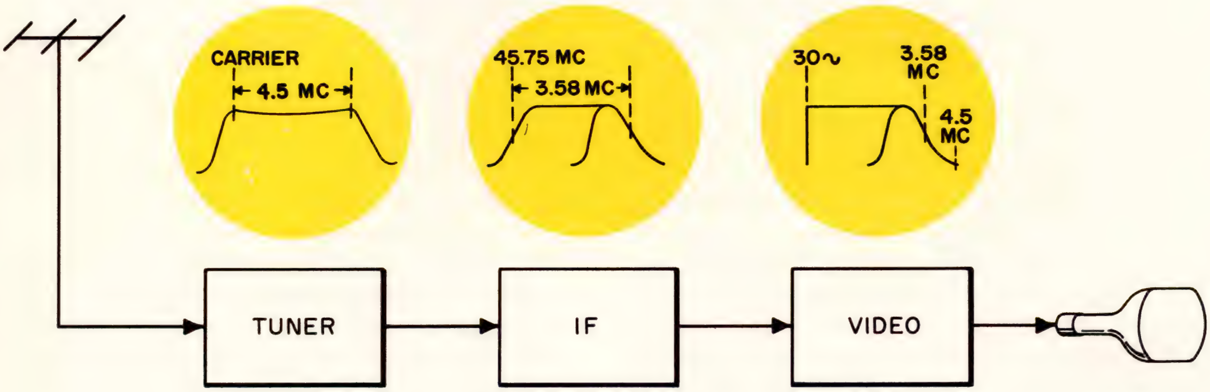


Figure 2-26. Block Diagram of Black-and-White Receiver

We now have a situation where the three color grids have no signal on them, but the cathodes of the three guns have a one unit or a 100% signal on them. Each of the guns is turned on 100%, which will give us a white raster, duplicating the original scene.

Figure 2-26 shows a color signal going through a black and white receiver. The bandwidth response of the various stages is shown, but since the color information is low visibility information in the brightness channels, it will not be seen on the black and white screen. The output of the video amplifier will produce a signal on the cathode of the black and white picture tube, which represents the brightness level of the scene being transmitted in color. This will be a 100% signal for a white transmission, a 59% signal for a green transmission, a 30% signal for a red transmission and a 11% signal for a blue transmission.

As mentioned above, the 3.58 mc color subcarrier frequency was picked so that it would be a low visibility signal if received on a black and white television screen. The relationship of the subcarrier to the horizontal scanning frequency is an odd harmonic of ½ the horizontal sweep frequency. This arrangement allows the 3.58 to cancel itself

on the television screen on successive scanning lines. Figure 2-27 illustrates this.

Here is shown two successive horizontal scanning lines, line #1 and line #3. Since our television system uses a 2:1 interlaced method, the odd numbered lines are scanned on one vertical field, and the even numbered lines are scanned on the next field. Line #1 and line #3 would be successive lines on this particular field.

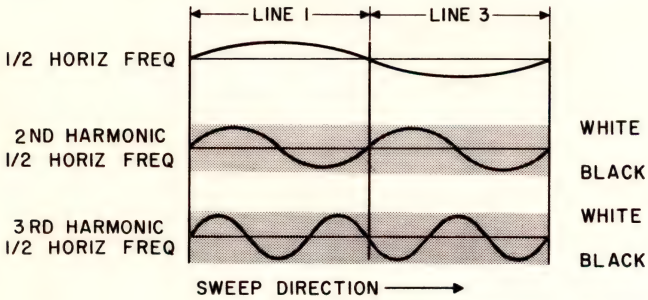


Figure 2-27. Suppression of Color Sub-Carrier in Brightness Signal

At the top of the illustration, we show that a signal representing ½ the horizontal sweep frequency (7,867 CPS) would require two successive scans to complete one cycle. The center illustration shows that the second harmonic of 7,867 CPS would complete one full cycle for each scan line and would add on successive lines. This signal is going toward the white level at the start of each line so would be visible as white on the left side of the screen and black on the right side of the screen.

The bottom illustration shows the third harmonic (odd harmonic) of 7,867 CPS which makes the screen go white at the start of line #1, but dark at the start of line #3. This would cancel out on successive lines and not be visible.

The exact color subcarrier frequency is 3.579545 mc and is the 455th harmonic of ½ the line frequency. To make this come out correctly, the horizontal sweep frequency on color transmission is changed to 15,734.3 CPS. In order to keep the 262.5:1 relationship between the horizontal and vertical sweep rates, which is necessary to maintain stability in synchronizing, the vertical sweep rate is changed to 59.94 CPS. Both of these new sweep rates are well within the tolerances of the receiver.

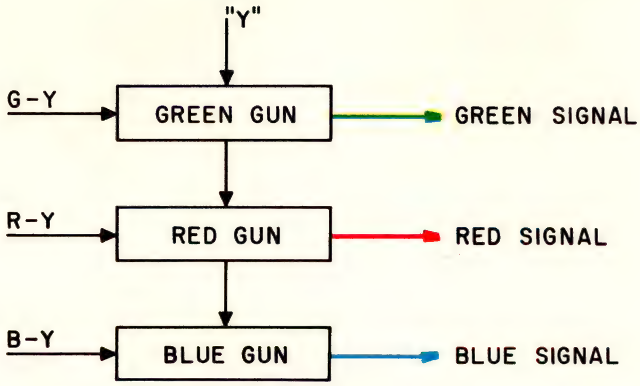


Figure 2-28. Combining Color Difference Signals with Brightness Signal in Guns to Produce Colors

The same conditions exist in the color receiver, which practically eliminates the visible effects of any color subcarrier appearing on the cathodes of the color picture tube.

In the foregoing, we examined a color transmission system that is compatible to black and white receivers. The black and white signal, which is made up of 59% of the green camera output, 30% of the red camera output and 11% of the blue camera output, contains all the brightness information and all the wide band high resolution information. This is referred to as the "Y" signal.

A color subcarrier, 3.58 mc away from the video carrier, contains hue information by the nature of its phase relationship to a burst of reference 3.58 mc signal, and saturation information by the amplitude of the subcarrier.

In the color receiver (Figure 2-28), the brightness ("Y") signal is received in the same manner as it is in a black and white receiver and sent to the cathodes of the picture tube. The color subcarrier is sent to demodulator circuits where it is separated into the R-Y, B-Y and G-Y signals which are put on the three grids of the color tube.

On the green gun, a "Y" signal appears on the cathode and a G-Y signal on the grid. Adding these two signals together we get G, or the green signal [Y+(G–Y)=G].

On the red gun, there is the "Y" signal on the cathode and the R–Y signal on the grid which when added together give us the R or red signal [Y+(R–Y)=R].

The blue gun has the "Y" signal and the B–Y signal which equals B, or the blue signal [Y+(B–Y)=B].

3 / Color Receiver Circuits

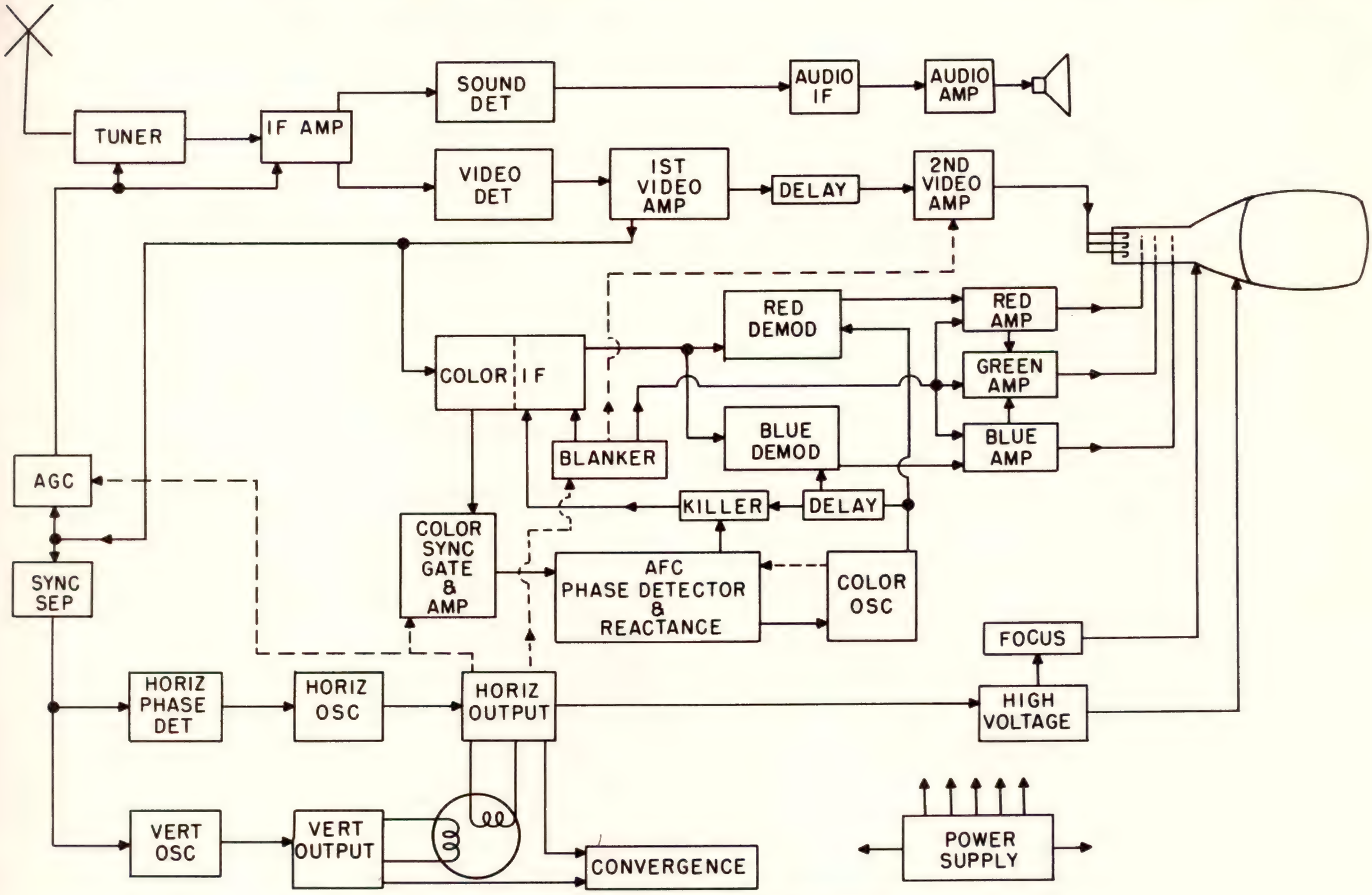


Figure 3-1. Block Diagram Color Receiver

We have looked at block diagrams for the color system to understand the overall process of color reception, so let us now examine specific receiver circuits and see how they function. In order to do this properly, we will enlarge the block diagram of the receiver to include all of the sections not previously discussed, and consider in detail the sections that are unique to color reception.

Figure 3-1 shows the complete receiver block diagram with the antenna on the left side and the speaker and picture tube on the right side.

Tuner

The function of a tuner is to select one transmitted signal out of a total possibility of 82 (VHF and UHF) signals, and convert this signal to an intermediate frequency (IF) to be amplified to a useful level. The frequency response of a tuner for color reception needs to be better than that for a black and white signal since we are concerned with the video carrier at one end of the spectrum and a relatively weak color subcarrier near the other end. Figure 3-2 shows the relative location of the signals that are transmitted for a color broadcast.

There are two considerations that are important in a tuner for color. The first is the Voltage Standing Wave Ratio (VSWR). This is the measurement of the match between the antenna and the grid of the RF tube. The lower this ratio, the better is the transfer of signal from the antenna into the receiver.

The second consideration is the noise figure of the tuner. Noise figure, expressed in DB, is the measure of the amount of noise inherent in the circuit. This could be seen on the screen as busy background or snow. Special frame grid triode tubes, as well as other unique triode tubes, have been developed to reduce the noise figure of the RF amplifier. This allows greater amplification of the signal without excessive noise.

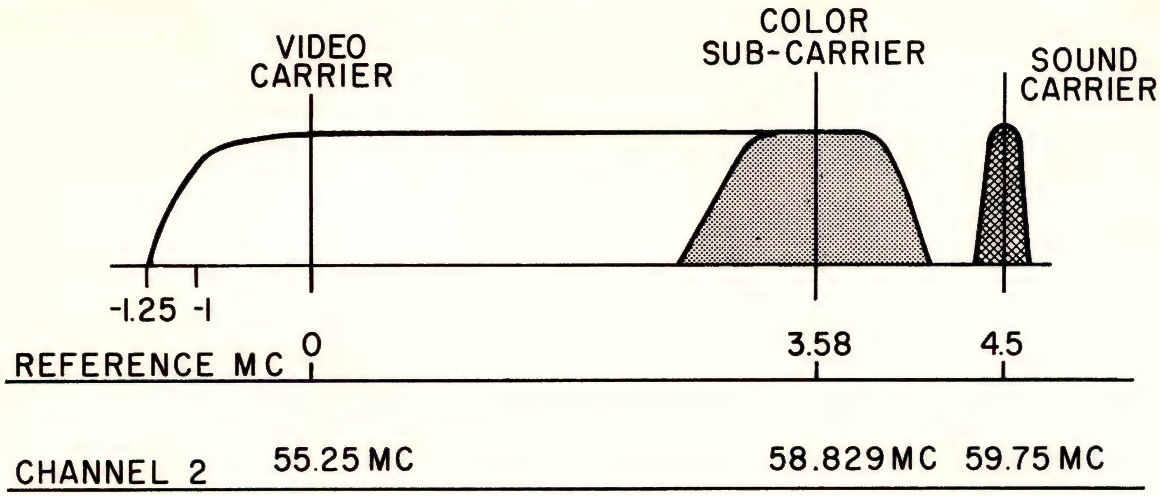


Figure 3-2. Relative Location of Transmitted Signals

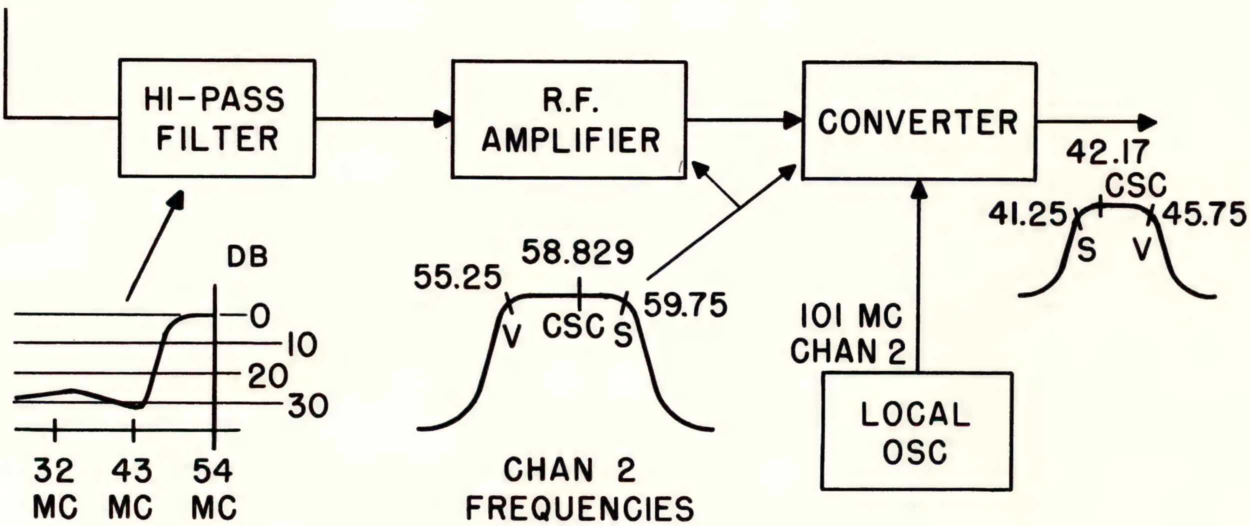


Figure 3-3. Tuner Functions

Figure 3-3 shows the function of the tuner. Between the antenna and RF grid, there is a highpass filter network, which is designed to keep out unwanted signals. This filter is usually tuned for maximum rejection at the IF center frequency, and rejects interfering signals in the IF pass band frequencies.

The RF amplifier has tuned circuits in its input and output, allowing it to amplify the total transmitted information for one channel. A channel selecting device, either in the form of a switch or a continuously tuned arrangement, allows the tuner to receive just one channel at a time. Figure 3-3 shows the bandpass characteristic of the RF amplifier when tuned to channel 2. This amplified RF signal is impressed on the converter stage. The converter tube is usually a dual section tube, with one section a pentode mixer-amplifier, and the other section a triode oscillator.

The tuning of the local oscillator is ganged with the RF tuning so that the local oscillator will always be 45.75 mc higher in frequency than the received video carrier. When tuned to channel 2, the local oscillator frequency will be 101 mc. The mixer section of the converter tube combines the RF and the local oscillator signals which forms a third signal, called the IF. This IF (intermediate frequency) will be the difference frequency between the transmitted signal and the local oscillator.

Since the IF frequency is the difference frequency between the local oscillator and the RF signal, we can subtract the various carrier (or the subcarrier) frequencies from the local oscillator frequency, to determine where these carriers will appear on the IF signal. The output bandpass response of the converter is shown in Figure 3-3 with the location of these carriers.

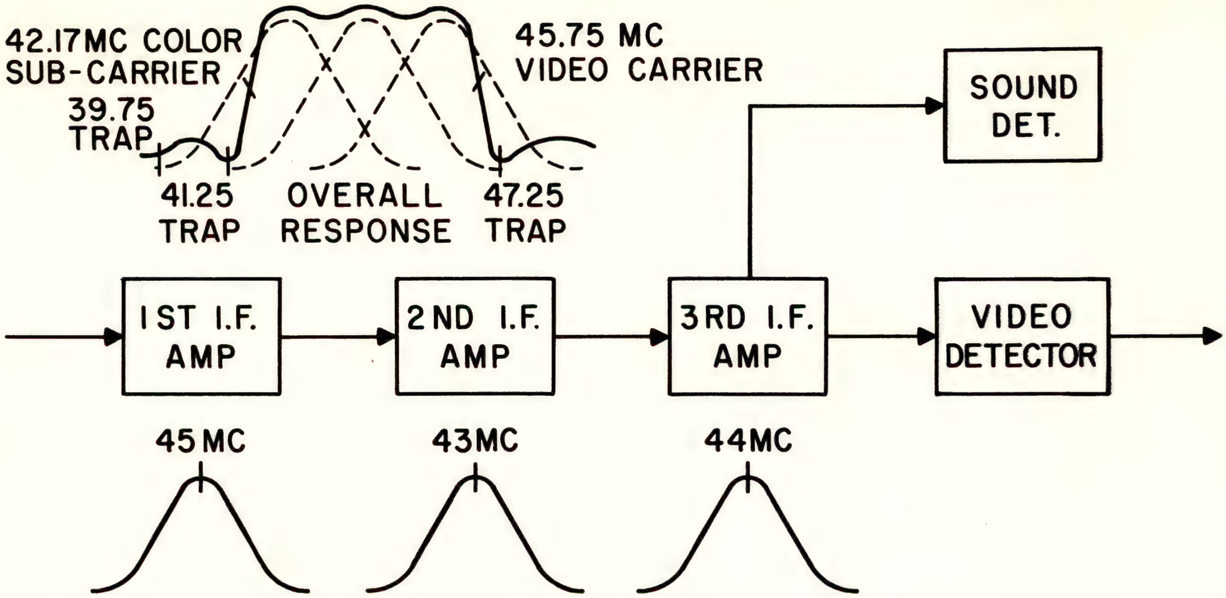


Figure 3-4. Stagger Tuned I.F. Response

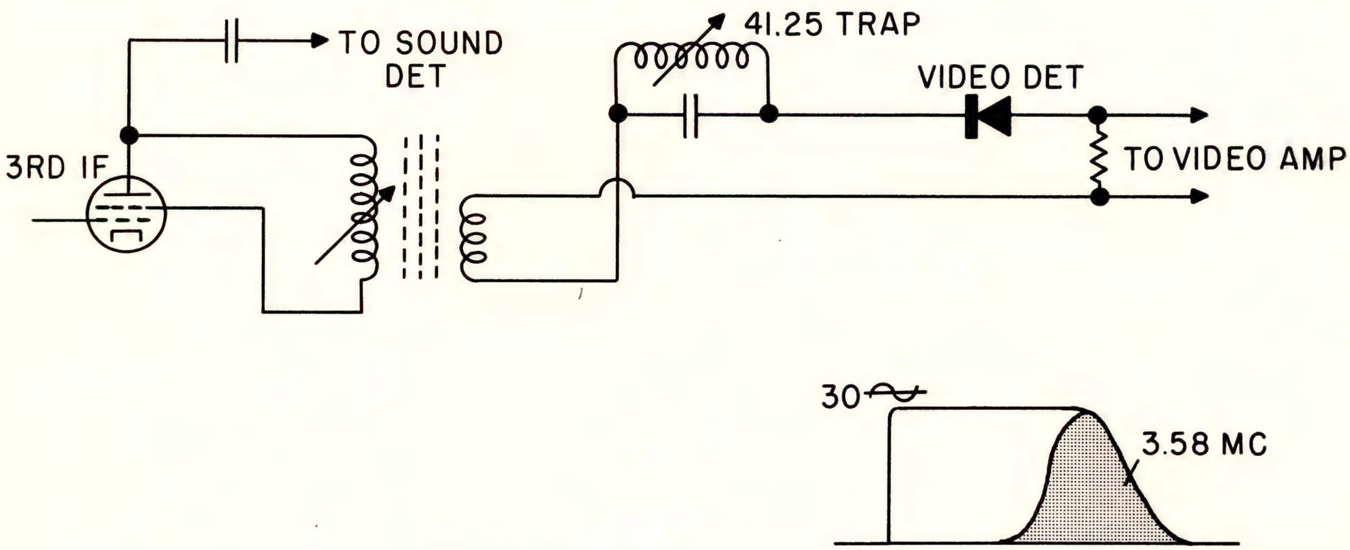


Figure 3-5. Sound Take-Off and Video Detector

IF Amplifier

The IF amplifier consists of two or more stages which amplify and control the bandpass characteristics of the signal. It is necessary that the IF amplifier pass the wide band of frequencies that compose the video signal. These individual stages are usually stagger tuned. Figure 3-4 shows this arrangement.

A convenient way of getting a wide band response is to peak each of the stages at a different frequency over the range of bandwidth desired. By peaking the first IF stage to 45 mc, the second IF stage to 43 mc, and the third IF stage to 44 mc, we obtain the waveform as shown at the input of the video detector.

Trap circuits in the IF are used to reject adjacent channel sound and video information and also serve to shape the bandpass as shown in Figure 3-4. In a color receiver, the sound IF beat note which appears at 41.25 mc point is trapped out rather sharply to prevent an objectionable beat note between the sound carrier and the color subcarrier.

In order to successfully trap out the sound IF carrier, without affecting the reception of the sound in the receiver, the sound signal is generally taken off somewhere in the third IF stage and treated separately from this point on. One method is that shown in Figure 3-5. The sound information is taken

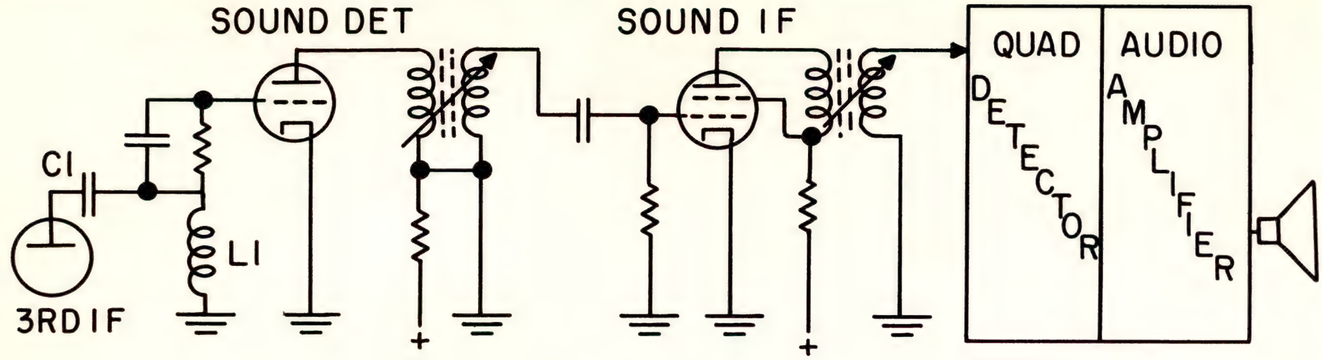


Figure 3-6. Sound Detector and I.F.

from the plate of the third IF stage, before the 41.25 mc trap, and fed into its individual circuits. The secondary of the third IF transformer includes a parallel resonant trap tuned to 41.25 mc and is inserted in series with the video detector diode. This trap is a high Q, high attenuation circuit which will sharply limit the amount of energy at 41.25 mc appearing in the video detector circuit.

Sound Circuits

Since the IF amplifier is wide bandwidth, it amplifies both the sound and video carrier information. These two IF carriers will be present in the plate of the third IF stage. In the inter-carrier sound system, which is now universally used, the beat note between these two IF carriers is used to give a 4.5 mc sound carrier. From the plate of the third IF tube, Figure 3-6, these carriers are fed into the input of a grid leak detector circuit, and the 4.5 mc hetrodyne is recovered in the plate circuit. The video carrier is an AM signal and the sound carrier is a FM signal, so when they beat together there will be produced a 4.5 mc beat note that is frequency modulated with the sound information. Tuned circuits at 4.5 mc determine the pass band which must pass the 50 Kc bandwidth sound signal. From this point on the sound is handled like a conventional television receiver, using a quadrature detector and an audio amplifier.

Video Amplifier

Figure 3-7 shows the basic circuit for a two-stage video amplifier, which amplifies the brightness, or the black and white component, of the televised scene. The output of the video detector is fed into the grid of the first video amplifier, with a 4.5 mc

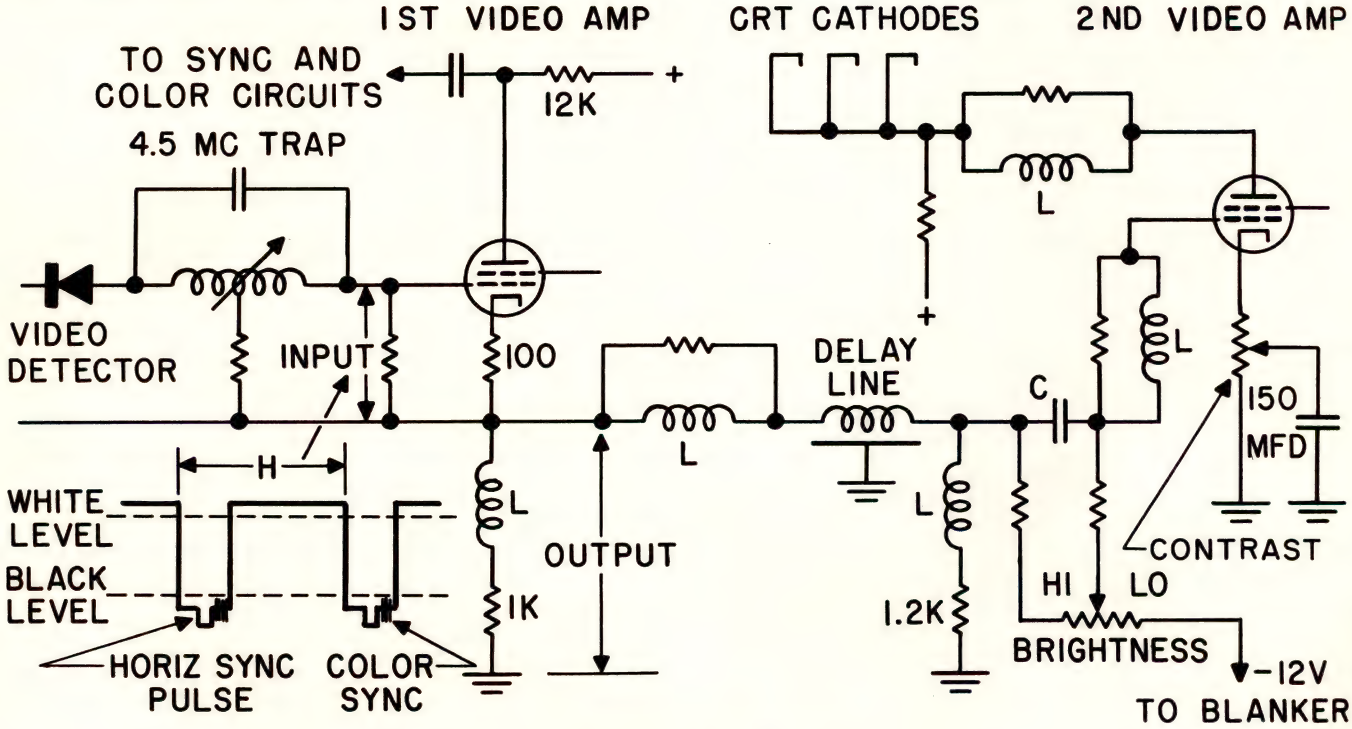


Figure 3-7. Video Amplifiers

high attenuation trap in between. Even though we trapped out the sound carrier (41.25 mc) in the output of the third IF stage, stray circuit capacities will allow some of these frequencies to still appear in the video detector, producing a 4.5 mc beat note with the video IF carrier. The presence of this 4.5 mc signal in the video amplifier along with our 3.58 mc color subcarrier, will produce an objectionable 920 Kc beat note which would be visible in the picture. Since we have no further use for the sound information in the video circuits, it is not only desirable but practical to eliminate it at this point. This trap should be very sharp (high Q) to prevent attenuation of any signals other than the unwanted 4.5 mc beat note.

The 1st video amplifier, in the Motorola color receiver, is a "bootstrap" configuration. In this type circuit the video detector output is applied between the grid and cathode, with the high resolution brightness signal taken off between cathode and ground. This has the appearance of being a cathode follower circuit, however it is not. With the arrangement shown in Figure 3-7, the 1K cathode resistor becomes part of the plate load resistance which allows us to realize gain without the normally expected phase reversal of the signal. The output is then taken off between cathode and ground, as indicated, and being a relatively low impedance point, makes available our high resolution, wide bandwidth, black and white or brightness signal.

In the plate circuit of the first video amplifier there appears the amplified video detector output which is used to feed the synchronizing circuits and the color IF amplifier circuits. These signals are narrow bandwidth, so no video peaking is provided.

The high resolution black and white signal from the cathode of the first video amplifier goes through a delay line enroute to the grid of the second video amplifier. Since transit time through an amplifier is inversely proportional to the bandwidth (frequency response) of the amplifier, signals going through a wide bandwidth amplifying system will reach the output before signals going through a narrow bandwidth amplifying system. In our color system we have the black and white information going through wide bandwidth circuits and the hue and saturation information going through narrow bandwidth circuits, therefore it is necessary to slow down the brightness signal so it will arrive at the picture tube at the same time the color signals arrive. The delay line slows down the black and white signal, or delays it in time by the necessary amount to insure that both color and black and white signals reach the picture tube at the same instant. Different circuit designs will require different amounts of delay which will vary between .6 and .9 microseconds. The delay line is a low impedance network since it is required that it delay all frequencies by the same amount, and can be fed directly from the low impedance output of the first video amplifier. The output of the delay line is terminated with a 1.2K resistor, which when combined with the brightness control resistance, matches the input impedance of the first video amplifier cathode resistor. Video peaking is accomplished throughout, by insertion of peaking coils "L" to maintain the wide bandwidth required.

Variable contrast control is obtained by moving a large electrolytic capacitor along the cathode resistor. This is accomplished by making the cathode resistor of the second video amplifier stage a carbon control with the arm connected to a 150 mf capacitor. When the arm is at the cathode end, the cathode is at AC ground and we have maximum AC gain through the tube. As the contrast control is moved toward the bottom or ground end, the unbypassed cathode resistor allows degeneration to develop in both the input and output circuits, minimizing the AC gain of the stage. The output of the second video amplifier is effectively connected to all three cathodes of the picture tube, connected in parallel.

The video amplifier system as shown here is 60% DC coupled. This means that DC voltages developed across the cathode resistor of the first video amplifier, which are caused by the changes in the blanking level of the transmitted signal, will affect the brightness level on the picture tube only 60% as much as if the system were 100% DC coupled. An example of this would be if the station were transmitting a completely white raster of one unit brightness, and the brightness control in the second video amplifier stage were set so that the screen of the picture tube was at one unit brightness. When the station then went to a black raster, or increased the amplitude of their signal to the black level point, the picture tube in the receiver would not go completely black but would still show a gray raster which would be approximately 40% as bright as the original brightness setting. This is accomplished by effectively applying the cathode voltage of the first video amplifier to the top end of the brightness control, and returning the bottom of the brightness control to a source of low regulation negative voltage. As the DC voltage on the first video amplifier cathode goes up and down due to picture content, the DC voltage on the grid of the second video amplifier stage will fluctuate up and down with this voltage, but to a lesser degree. The AC component, or the video information, is coupled directly into the grid of the second video amplifier through capacitor C. By having such an arrangement, we are able to maintain the important DC component of the scene and still be able to tune in stations with different blanking levels and modula-

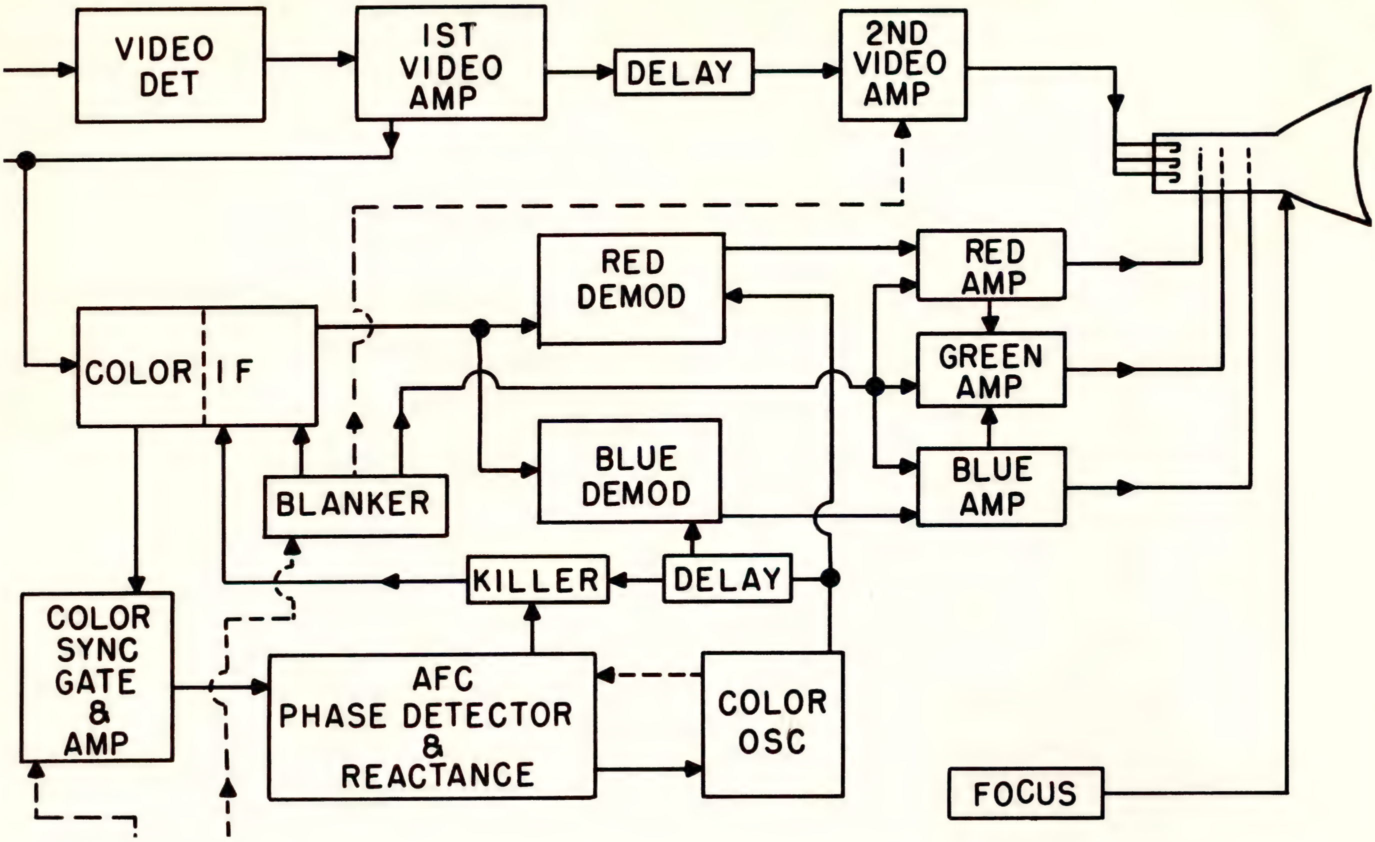


Figure 3-8. Block Diagram of Color Circuits

tion percentages without continually having to re-adjust brightness and contrast controls.

Color Circuits

Figure 3-8 shows a portion of the large color receiver block diagram, emphasizing the circuits necessary to receive color.

From the plate of the first video amplifier, the composite video signal is fed to the color IF block. In this stage we are interested in amplifying the color subcarrier which apears as a 3.58 mc signal. Figure 3-9 shows the simplified circuit using two stages of amplification. The input coil is peaked near 4 mc so that the 3.58 and 3.0 mc points will be on the leading slope. This is done so that the color IF input response will complement the high frequency end of the video response, making the actual input response as shown in 3-10:1. Also, by having this circuit peaked to the high frequency end of the video spectrum, the low frequency brightness information is rejected from the circuit.

The color subcarrier is amplified in the first color amplifier stage, Figure 3-9, with the output of this stage coupled to the grid of the second color IF amplifier through a double-tuned transformer. This transformer further shapes the bandpass response to the desired bandpass characteristics. A gain control is provided in the grid of the second color IF stage to allow the viewer to control the amount of color present on the screen. This is the intensity control.

The output of the second color IF tube is coupled through an untuned transformer to the grids of the two demodulators, where the color subcarrier will be converted into color difference signals. Figure 3-10:2 shows the amplified color signal for one horizontal line from a standard NTSC color bar generator.

Demodulators

The purpose of the demodulator is to take the radio frequency color subcarrier and convert it into a video voltage which will duplicate the voltages that were produced by the color signal at the transmitter. Since the color subcarrier is a varying amplitude AC voltage, whose phase is variable according to some standard phase, we need a source of standard phase voltage with which to compare it. For this reason we show in Figure 3-11, the red and blue demodulators along with the color oscillator block.

In the transmitter, our color subcarrier was created by combining the output of the red and blue balanced modulators. The blue balanced modulator was excited by a reference voltage of zero degree

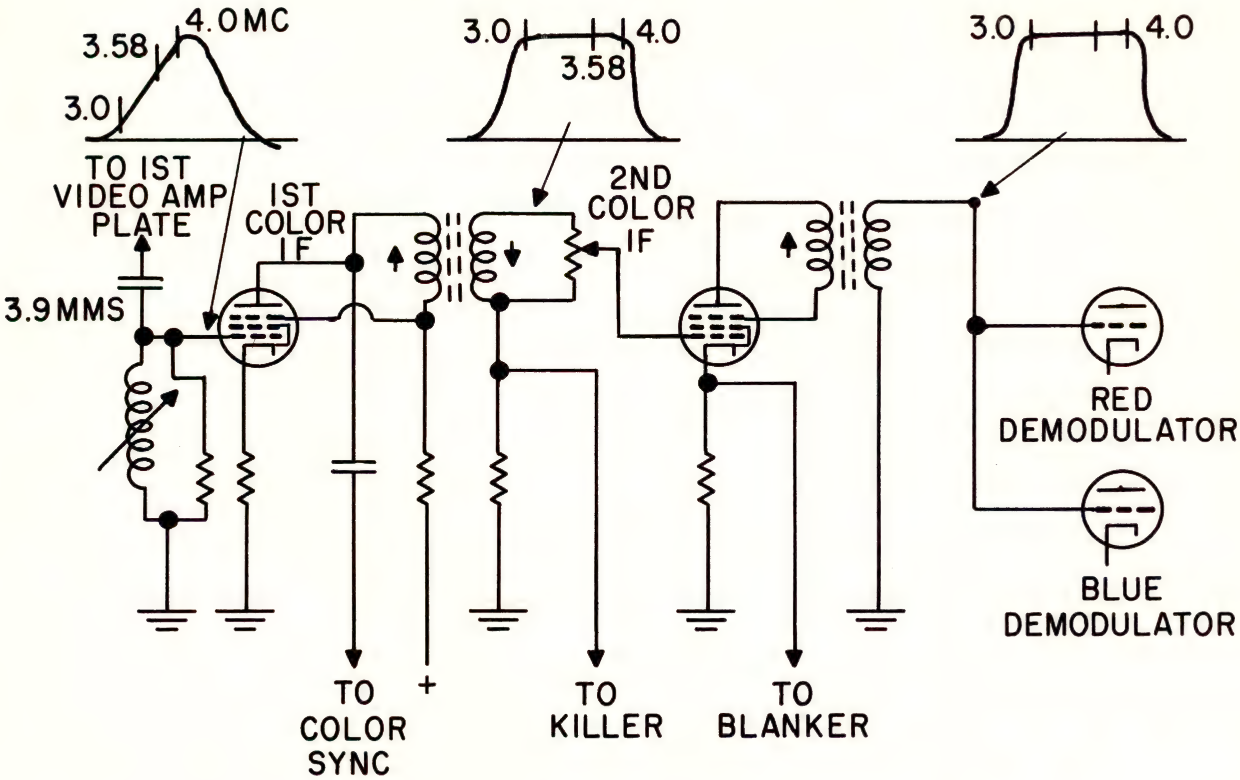


Figure 3-9. Color I.F.

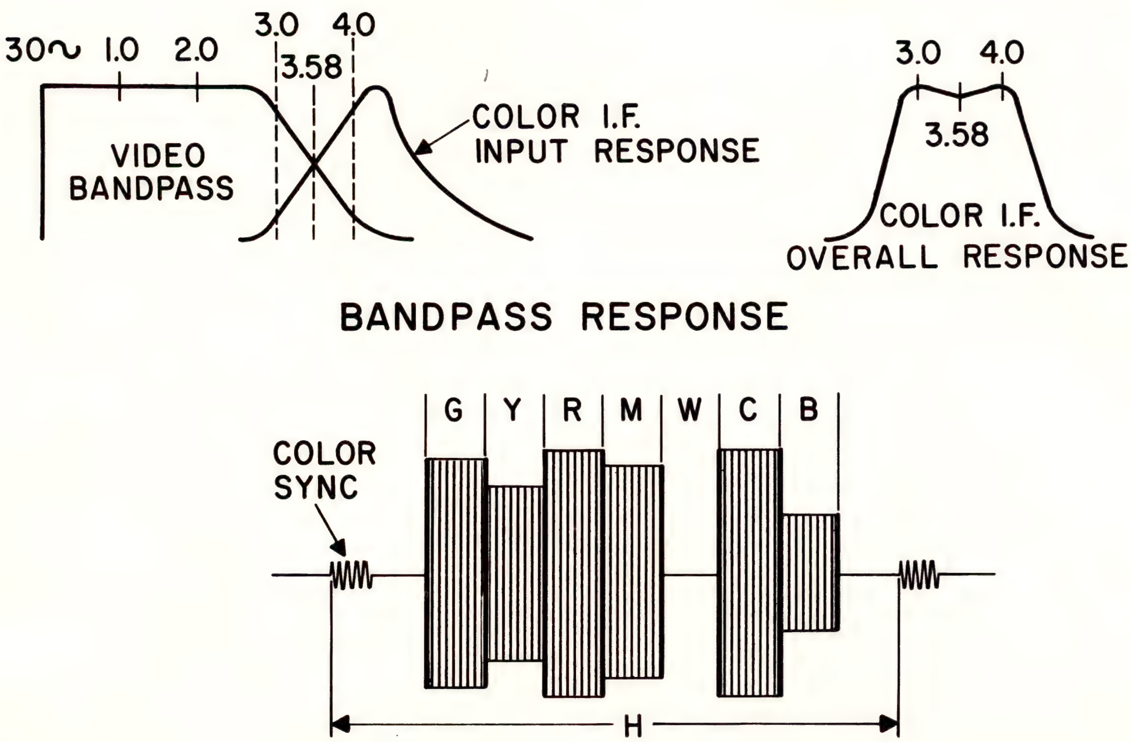


Figure 3-10. Color Signal From NTSC Color Bar Generator

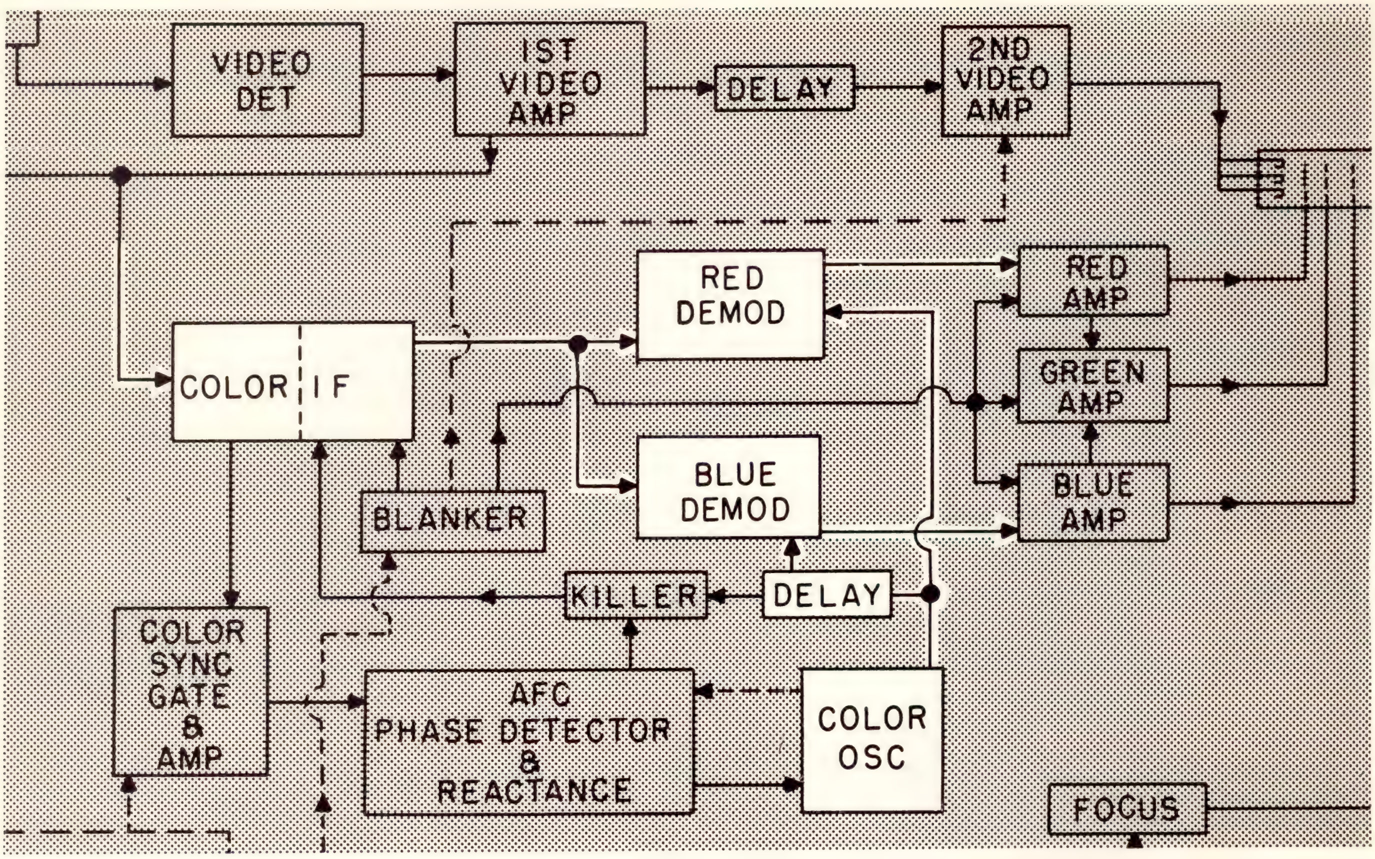


Figure 3-11. Block Diagram of Demodulators and Color Oscillator

phase and the red balanced modulator was excited by an AC voltage of 90° phase. In our demodulation system it is necessary to compare the received color subcarrier with the same two phases of oscillator signal that we have at the transmitter, and reverse the process of when the signal was formed. This means that we compare the incoming color subcarrier with oscillator phases of 0° and 90°, and produce video frequency voltages which can be used to excite the color picture tube.

Figure 3-12 shows the simplified schematic of a triode demodulation system. There are several different types of color demodulators, with the triode type shown here being one of the most practical. All color demodulators are known as synchronous demodulators since their function is to provide an output voltage determined by the comparison of two AC voltages of the same frequency, but of different phases. The synchronous feature comes from the fact that the locally generated oscillator signal in the receiver is locked exactly in phase and frequency with the oscillator that excites the color circuits at the transmitter. To see how the demodulator works we will assume briefly that the 3.58 crystal oscillator in Figure 3-12 is at exactly the same frequency and phase as the oscillator at the transmitter.

We will now do the opposite of that which was done at the transmitter. There we took signals along a R-Y and a B-Y axis, combined them to make a resultant sinewave which was transmitted as the color subcarrier. In the receiver we take this resultant subcarrier phase and return it into its R-Y and B-Y components. Figure 3-12 shows the red triode demodulator with the 90° phase oscillator signal injected into its cathode, and the blue triode demodulator with 0° oscillator signal injected into its cathode. Into both of the grids we apply the output of our color IF which, in this example, is a color subcarrier with a phase of 90°.

In order to have the demodulator produce an output proportional to the amount of color subcarrier falling along its exciting voltage axis (with a minimum of distortion), it is necessary for the exciting voltage to be 5-8 times the amplitude of the input color subcarrier. In the case of the red demodulator, the amplitude of the 90° oscillator signal fed to the cathode would be in the order of 15 volts peak to peak, while the subcarrier signal on the grid would be in the order of 3 volts peak to peak. The bias is adjusted on these two demodulators so that with no signal into the control grid, the oscillator injection on the cathodes cause the tubes to conduct slightly or just enough to have

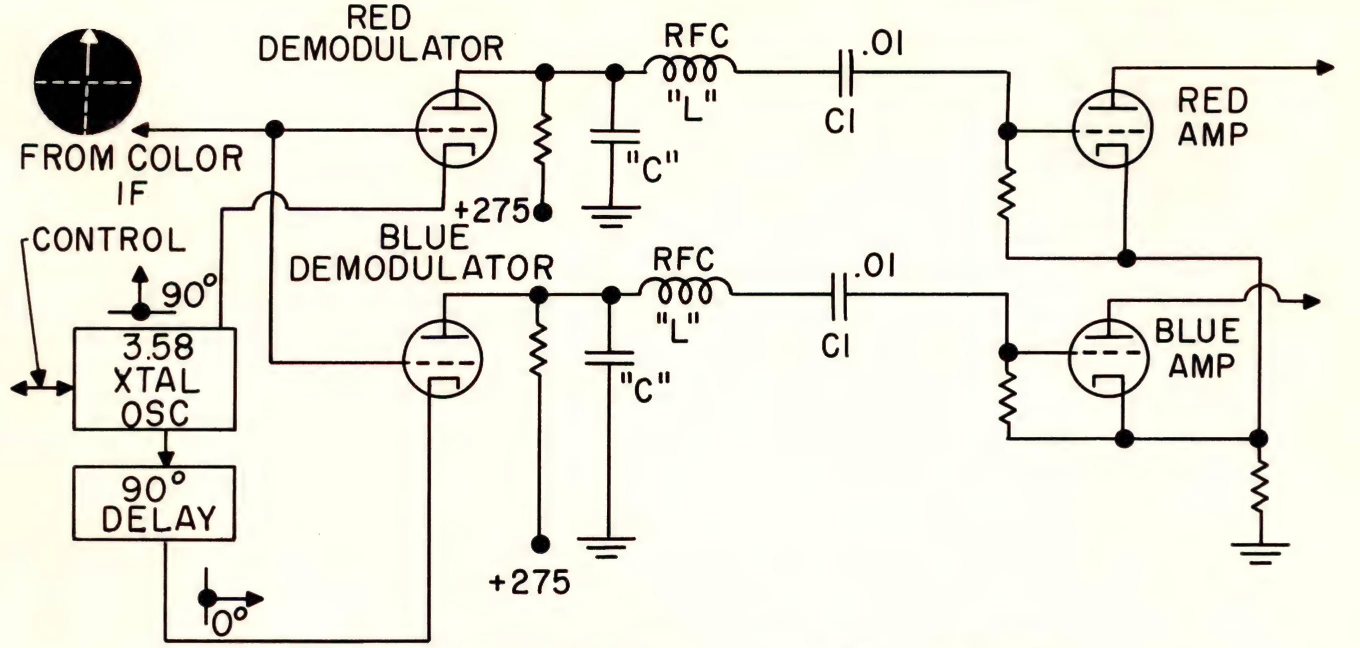


Figure 3-12. Red and Blue Demodulators with Color Difference Amplifiers

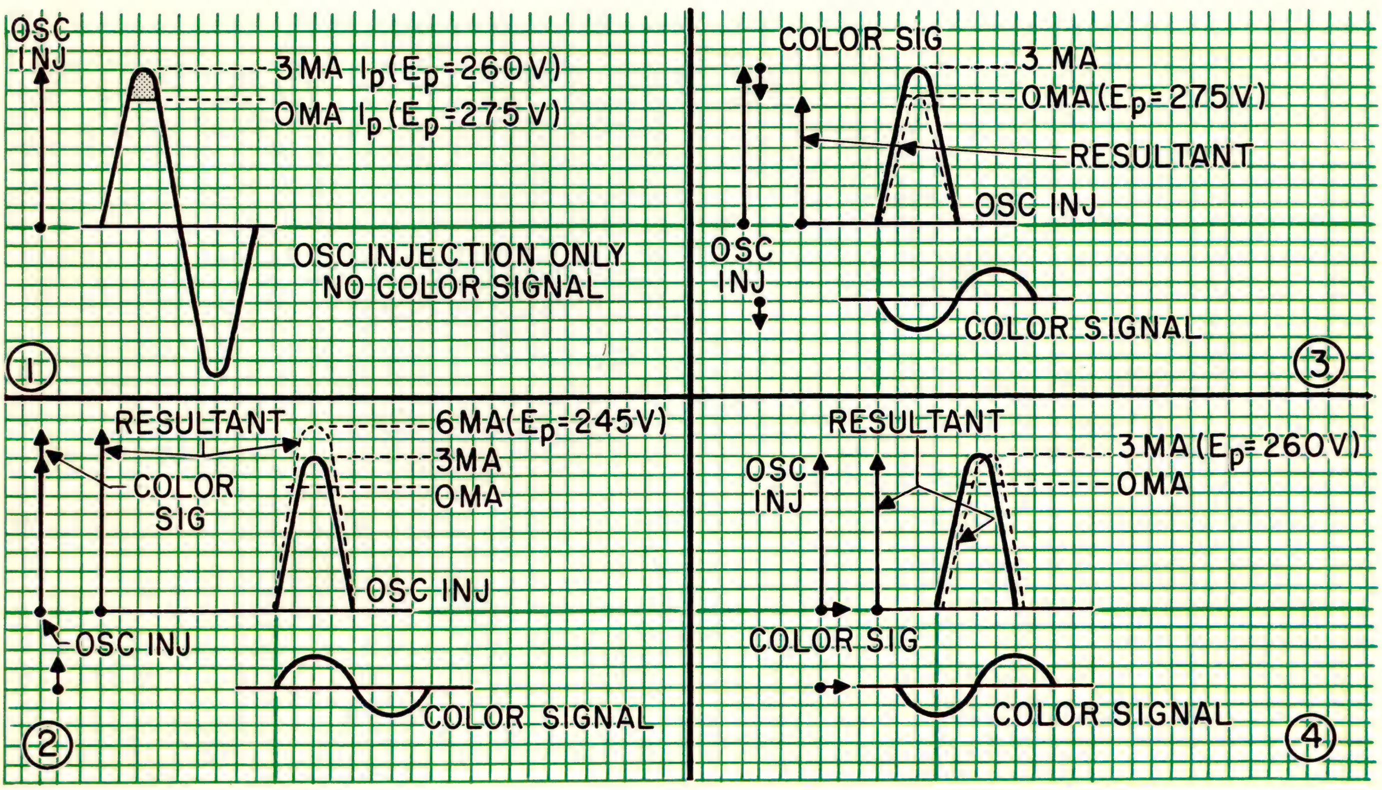


Figure 3-13. Action of Signals in Demodulator

about 15 volts drop across the plate load resistor. This means that just the peaks of the exciting oscillator voltage is causing current to flow in the plate circuit. To make the illustration of this principle clear, we will show in Figure 3-13 how both the oscillator injection and color subcarrier appear in the plate circuit. The reason for this is that a negative going signal on the cathode is the same as a positive going signal on the grid, as far as the plate current in the tube is concerned. So, by showing these signals in the same polarity, the explanation of the principle involved is clearer.

Figure 3-13:1 shows that with only oscillator injection signal in the demodulator tube, the plate current reaches 3 milliamperes of current at the positive peak, causing a plate voltage drop of 15

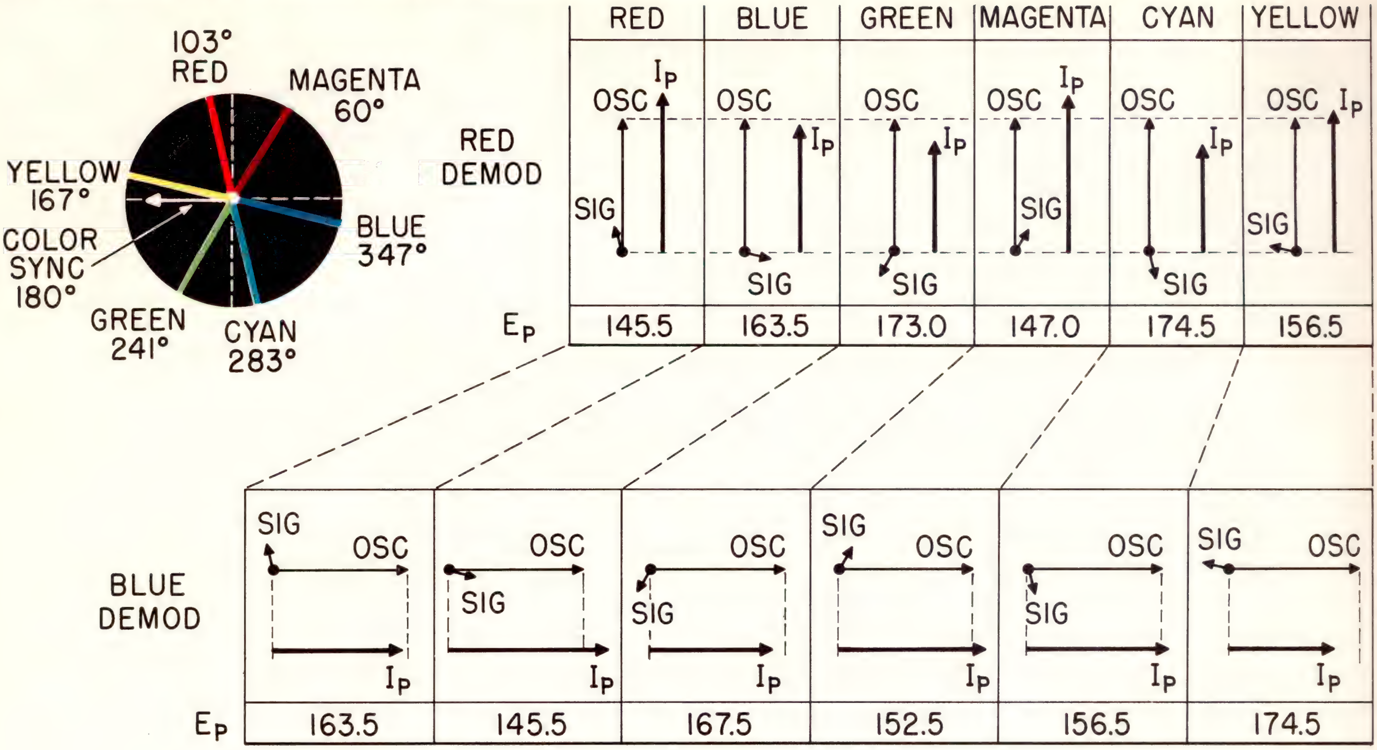


Figure 3-14. Signals In The Modulator

volts. The LC filter network in the plate circuit (Figure 3-12) filters out the AC signal and will give us an average plate voltage across the coupling capacitor, C-1, of 260 volts. This 260 volt point will then become our zero or AC axis for whatever effect the color subcarrier signal would cause on the plate current of the tube.

Figure 3-13:2 shows what will happen when an in-phase color signal is applied to the grid. It will add to the effect caused by the oscillator injection signal, causing an increase in plate current. Where the average plate voltage for no signal was 260 volts, the addition of the color signal on the grid of the demodulator causes the plate current to now rise to 6 milliamperes, dropping the plate voltage to 245 volts.

In Figure 3-13:3, we show the effects of adding an out of phase signal on the grid of the tube. This will have the effect of canceling out part of the oscillator injection signal and give the resultant as shown. This will reduce the plate current to zero allowing the voltage across the capacitor C-1 to rise to the full supply voltage of 275 volts.

Figure 3-13:4 shows the effect of a color subcarrier signal that is 90° displaced from the injected oscillator signal. The resultant will be displaced slightly in time, but the average current in the tube will. not change, and the plate voltage will remain the same.

A color signal that is in phase with the injected oscillator signal will cause an increase in plate current, with an associated drop in plate voltage; a color signal that is 180° out of phase with the injected oscillator signal will cause a decrease in plate current, with an associated rise in plate voltage; and a 90° out of phase color signal, either leading or lagging, will cause no change in plate current or plate voltage. A vector representation of this action is shown in each of the three previous illustrations.

Figure 3-14 shows the fully saturated primary and complementary colors and the phase angle of the color subcarrier which represents these colors. The vector analysis in this Figure shows how each of the primaries act in each of the demodulators and the resultant voltage outputs.

Figure 3-15 shows the output waveform of the red and blue demodulators when a color bar pattern is transmitted. As shown, the sequence is a green bar, yellow, red, magenta, white, cyan and blue. There is no chroma information transmitted on the white bar so there will be no subcarrier during this interval. Figure 3-15 shows the signal occurring on the grid of the demodulators, and the DC voltage output of each of these demodulators and appearing across the capacitor C-1 in Figure 3-12.

These signals are then amplified by their respective red and blue amplifiers which invert the signal to give us the proper polarity to drive the grids of the color picture tube. These signals are shown in Figure 3-16.

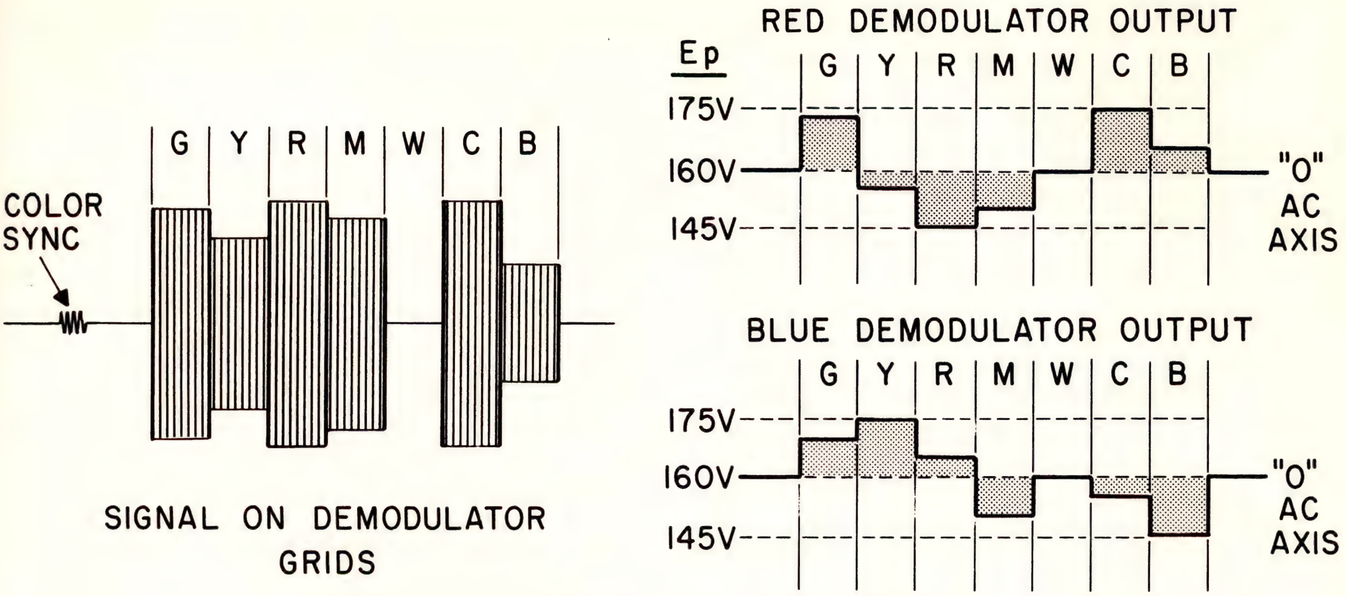


Figure 3-15. Demodulator Input and Output Signals

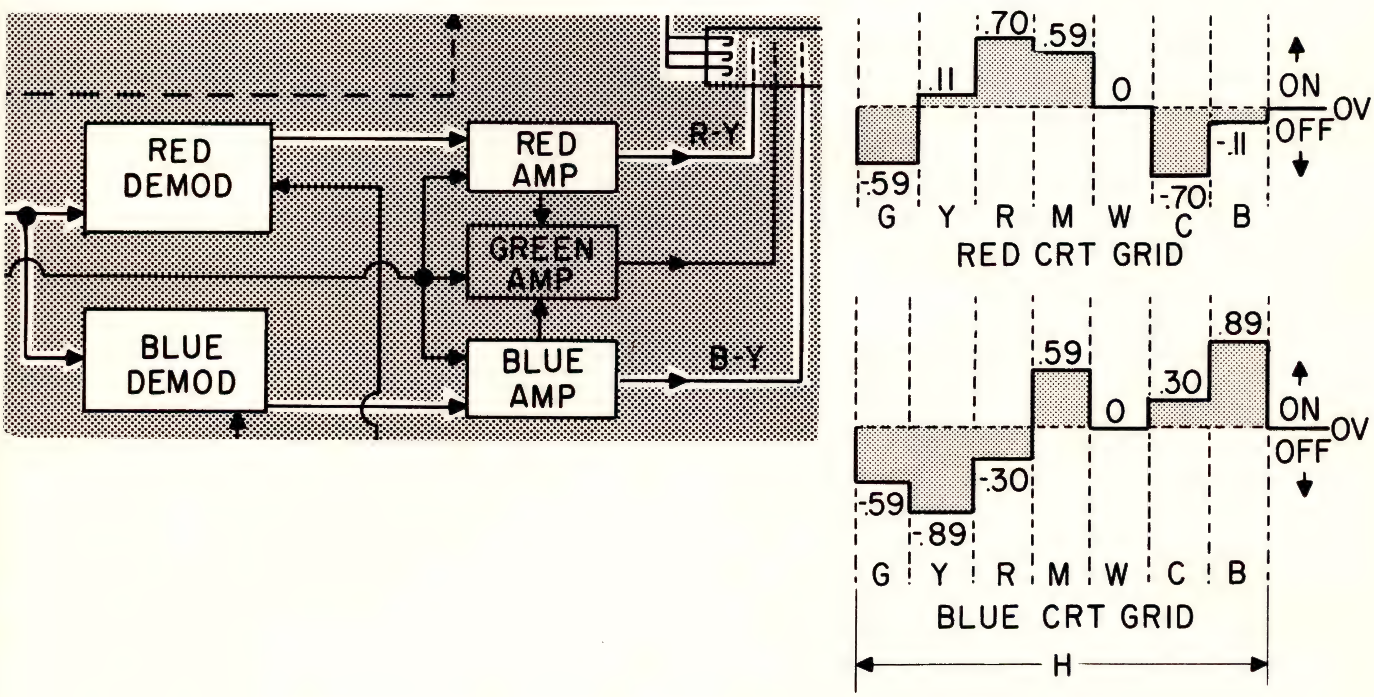


Figure 3-16. Red & Blue Color Difference Signals For NTSC Standard Colors

In an R-Y and B-Y demodulation system, green is recovered by taking a portion of each of the red and blue color difference signals. By taking 51% of the R-Y signal and 19% of the B-Y signal, combining them and then inverting this combination, we arrive with the G-Y signal. This is shown in Figure 3-17. In this illustration the −[G-Y] signal is fed into the grid of the green amplifier which inverts the signal and it becomes a positive quantity G-Y signal. In this illustration the green amplifier has a gain of 1, so that the output voltage will be the same magnitude as the red and blue amplifiers. The voltages necessary to drive the green picture tube grid for the various color bars transmitted is shown in Figure 3-17.

Figure 3-18 shows the driving signals on the color picture tube for the six saturated colors and white. These signals are shown in terms of "ON" and "OFF" signals rather than voltage polarities, because the brightness signal is applied to the cathode of

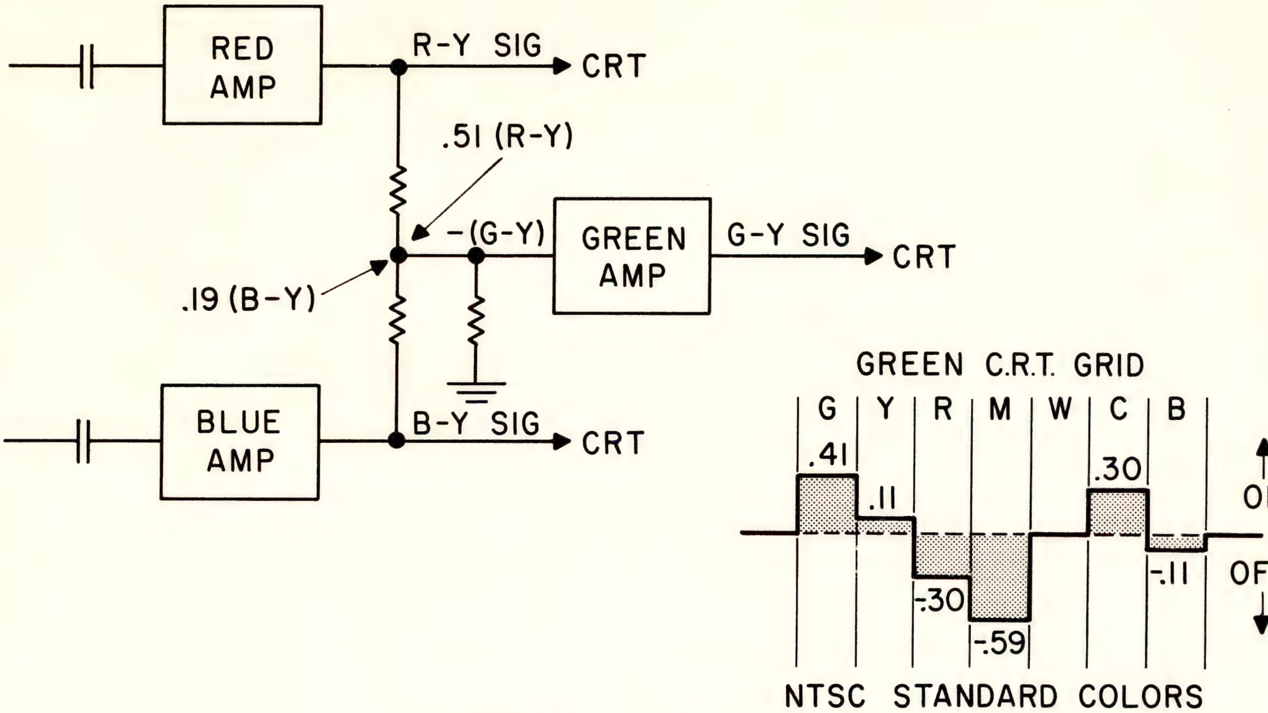


Figure 3-17. Recovery of G-Y Signal

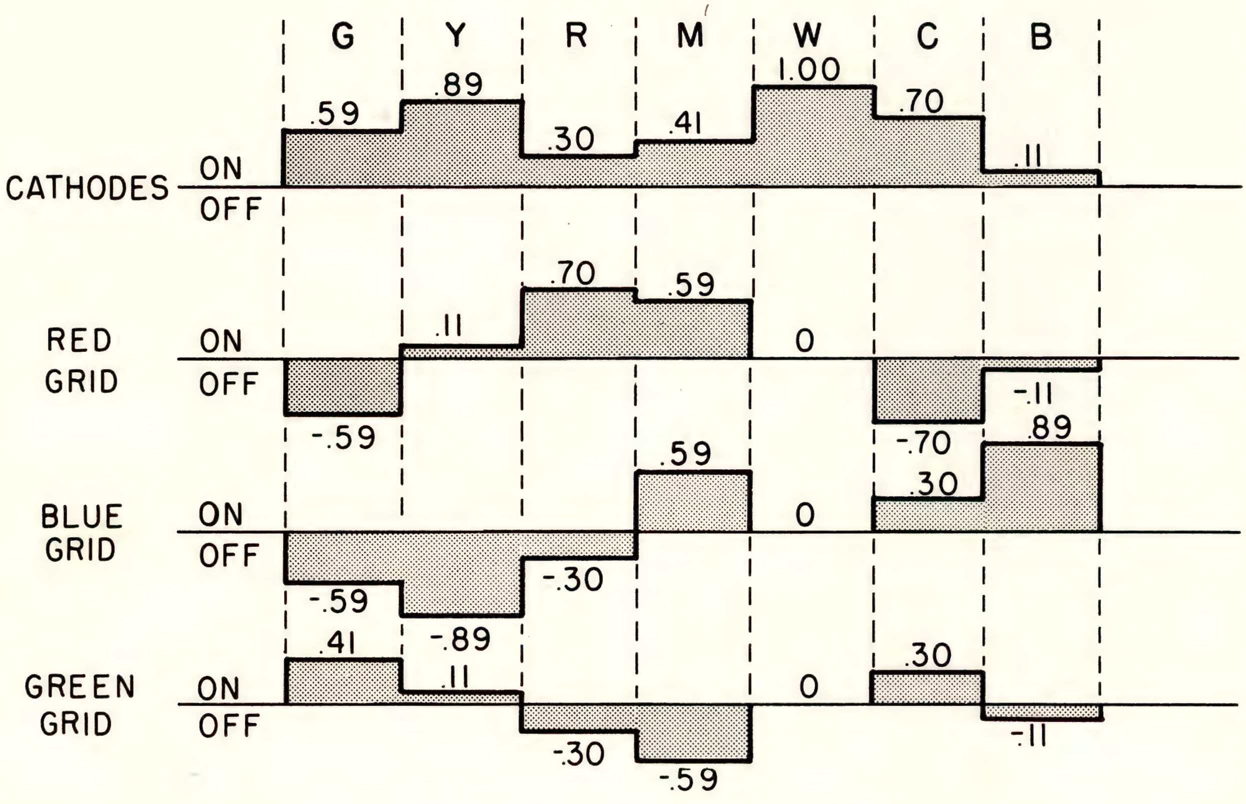


Figure 3-18. Driving Signal for Color CRT

the three guns while the color difference signals are applied to the individual grids. This means that a positive voltage on the grid would turn the gun on, while a negative voltage on the cathode would be required to turn the gun on; so this chart is captioned in terms of "ON" and "OFF".

The top column is the brightness, or Y signal, which is fed to all three cathodes to set the proper brightness for each color. If a green signal is transmitted, the "Y" signal fed to all three cathodes turns the three guns on by 59%. In the vertical column under green, we see that the red and blue

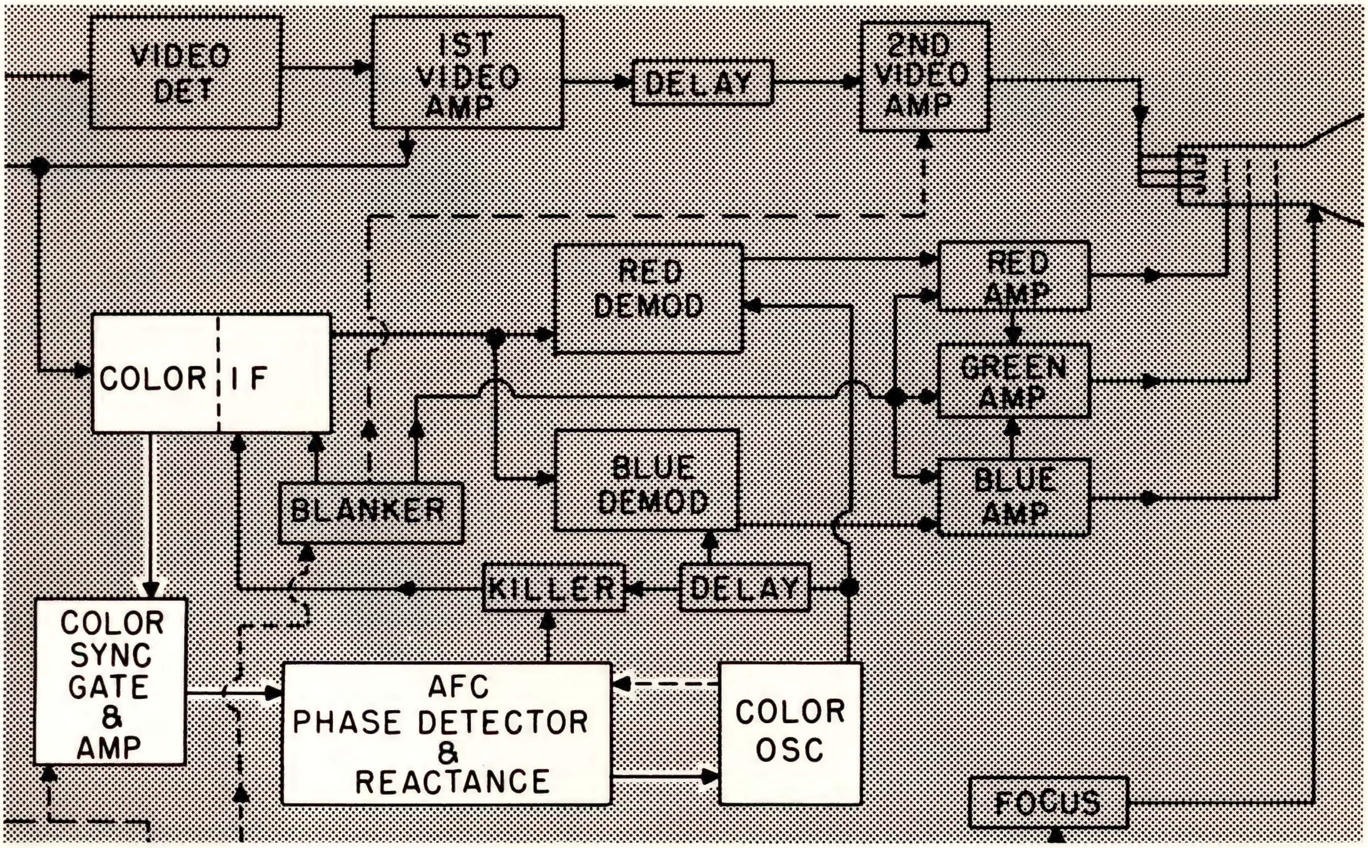


Figure 3-19. Block Diagram of Color Sync Circuits

grids receive a 59% "OFF" signal. When added to the 59% "ON" signal in each gun, it will cancel out, turning the red and blue guns completely off. The green grid will have a 41% "ON" signal on its grid, which when added to the 59% "ON" signal on its cathode will total 100% "ON" for the green gun and only green phosphors will be lit on the tube. The same is true for the other two primary colors, red and blue, except that the percentages of signals on the four elements will be different. In the case of the red bar, the brightness level appearing on the cathodes of all three guns will be a 30% "ON" signal. On the red grid will appear a 70% "ON" signal which when added to the 30% signal on the cathode, will turn the red gun on 100%. At the same time, there will appear on the blue and green grids a 30% "OFF" signal, canceling out the 30% "ON" signal on their cathodes, cutting these two guns off. Since the red gun is the only one operating, only red phosphors will be illuminated.

To reproduce the complementary colors of yellow, magenta and cyan, it is necessary that two of the guns be on 100% and one gun be off. For yellow, the red and green guns are on 100% and the blue gun is off. For magenta, the red and blue guns are on 100% and the green gun is turned off. For cyan, the blue and green guns are on 100% and the red gun is turned off. When white appears on the screen, this means that all three guns are on 100% and since no color subcarrier is transmitted on a white scene (as discussed in our examination of the transmitter), there will be no signal on the three grids, but we will have a 100% "ON" signal on the three cathodes causing all three guns to be on 100%. With this system, by varying the amount of drive signal on one or more of the guns, we are able to reproduce a range of colors and shades that exceed those available in color photography or color printing.

Color Synchronizing Circuits

Up to this point we have assumed that the color oscillator in the receiver was at the same phase and frequency of that in the transmitter. We will now examine the circuits that synchronize this crystal oscillator. Figure 3-19 shows the sections of the color block diagram we will now be concerned with.

Figure 3-20:1 shows the basic schematic for the color sync gate and amplifier circuits and the AFC phase detector circuit. The composite color signal is taken from the plate of the first color IF and fed to the grid of the sync amplifier tube. This tube is biased so that there is 200 volts on its cathode. A voltage divider to ground from the cathode supply voltage gives us a 190 volt point which is connected to the grid. Regardless of the signal into the grid,

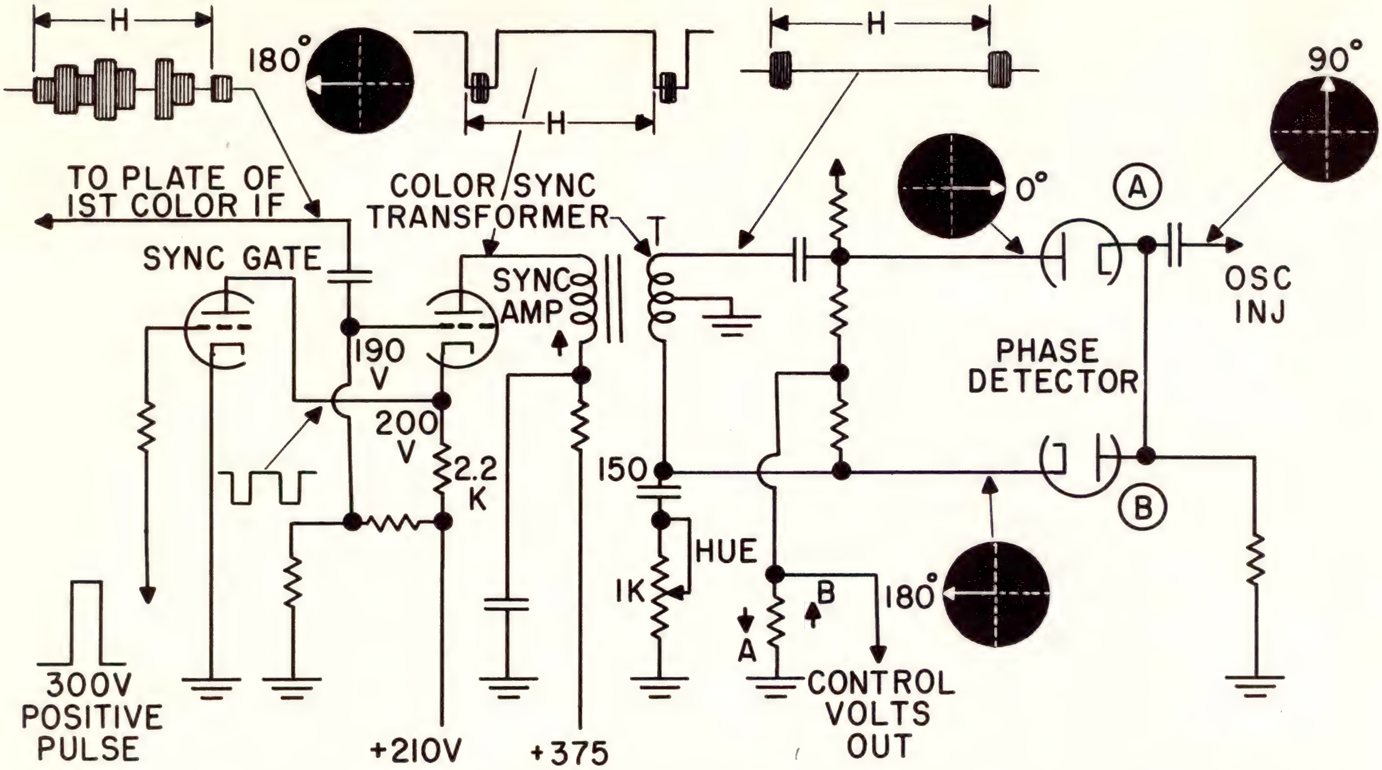


Figure 3-20:1. Color Sync Gate, Amplifier and A.F.C.

the negative voltage on the grid with respect to the cathode prevents any signal from appearing in the plate circuit, since no plate current is flowing.

The cathode of the sync amplifier is connected to the plate of the gate tube and the 200 volts on the sync amplifier cathode now becomes the plate voltage for the gate tube. Into the grid of the gate we feed a 300 volt positive pulse which comes from the horizontal output transformer, and occurs only during horizontal retrace time.

Examining the composite color signal on the grid of the sync amplifier, we find that the color synchronizing information happens during the retrace time of the beam, and will happen at the same time as the 300 volt pulse. When this pulse hits the grid of the gate tube it causes maximum current to flow through this section and causes the voltage to drop on the plate, and the cathode of the sync amplifier tube. When this happens the grid on the sync amplifier tube becomes positive with respect to the cathode of that stage and plate current will flow. This allows the color sync signal to be amplified in the sync amplifier since this is the only portion of the composite color signal that is present on the grid at the time of the 300 volt gating pulse. Immediately after the gating pulse has disappeared, the sync amplifier tube will then again be cut off, preventing any of the color information from appearing in the plate circuit. In the plate circuit of the sync amplifier tube, we will then see the waveform as shown in Figure 3-20:1.

Transformer "T" is a tightly coupled transformer tuned to 3.58 mc. The secondary is a center-tapped balanced winding and couples opposite phases of the color sync signal to the AFC phase detector diodes. The cathode of section A and the plate of section B are tied together and connected to the color oscillator. The phase of the oscillator signal at this point is 90°.

The phase of the color synchronizing signal is 180° as received, and through proper phasing of the sync transformer, is applied to the cathode of section B. Since the secondary of this transformer is a center-tapped winding, the opposite phase or 0° is applied to the plate of section A. Vectors representing the phase of the various signals on the phase detector diodes are shown in Figure 3-20:2. This illustration shows the total voltages appearing across each of these diodes for different sync conditions.

The first column shows the voltages across the diodes for an "in-sync" condition. Diode A has a 0° sync signal on its plate and a 90° injection signal on its cathode with the resultant voltage of E_A across the diode. When diode A conducts, electrons will flow from cathode to plate down through the center-tapped resistor toward ground through resistor R_L. This makes the top of resistor R_L negative with respect to ground.

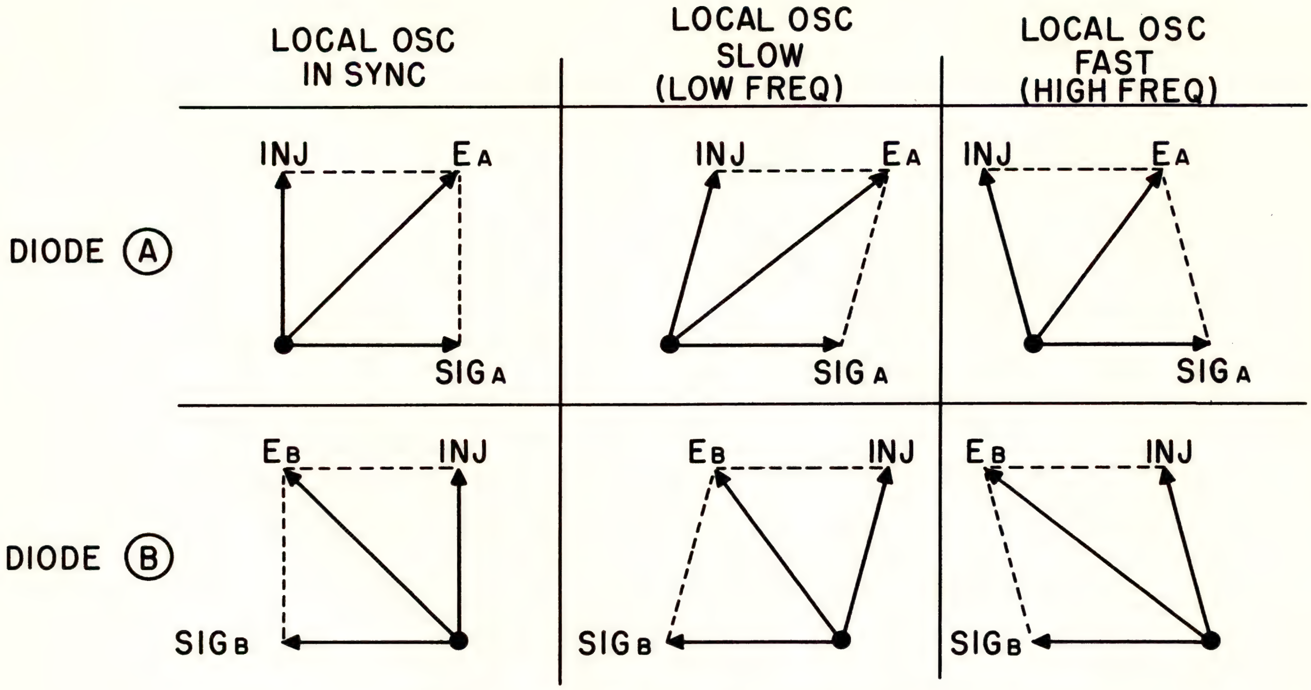


Figure 3-20:2. Signals of AFC Phase Detector for Different Local Osc. Frequencies

Diode B has the injection voltage on its plate and the 180° sync signal on its cathode, with the resultant total voltage across its diode represented by vector E_B. When diode B conducts, electrons will flow up through resistor R_L through the center-tapped resistor up to the cathode and over to the plate. Current flowing in this direction through resistor R_L will cause the top of this resistor to become positive with respect to ground. In the "in-sync" condition, the length of vectors E_A and E_B are exactly the same magnitude indicating that both diodes are conducting the same amount. The negative and positive voltage drops across R_L are equal and opposite, therefore, for the "in-sync" condition, the control voltage at that point would be 0 volts.

In the second column, we show what happens across each diode when the color oscillator is slow or low in frequency. This means that the injection vector will tend to lag or become less than 90°. When we compare the total voltages appearing across each of the diodes for this low frequency condition, we find that there is a greater amplitude across diode A than there is across diode B. As indicated by the length of resultant vectors E_A and E_B, we find that more current is passing through diode A than diode B. For this condition, more negative voltage will be developed across resistor R_L than positive voltage, and the output control voltage will be a negative voltage with respect to ground.

The last column (Figure 3-20:2) shows the voltages across each of the diodes when the oscillator is fast or higher in frequency. For this condition, the injection phase tends to lead the point that it normally holds when "in-sync" and we find that the resultant vector E_B is of greater magnitude than resultant vector E_A. This means that diode B will conduct more current than diode A, resulting in a greater positive potential being developed across resistor R_L. A positive control voltage is then developed when the color oscillator is running fast or higher in frequency than it should. These control voltages are then applied to the grid of a reactance tube and control the frequency of the crystal oscillator.

Hue Control

The hue control is a variable resistor in series with a small capacitor which is connected from one side of the color sync transformer to ground. Figure 3-20:1. This transformer is tightly coupled so that any loading on the secondary will reflect a tuning change in the primary.

This tuning change will have the effect of changing the phase of the color sync with relation to the rest of the color subcarrier. Since the phase of the local color oscillator is determined by the phase of the color sync, the oscillator injection into the demodulators will also be changed. This will allow us to make corrections in the colors that are received (specifically flesh tones) that may vary from station to station and from the different types of program origins; ie., video tape, film and/or live pickup.

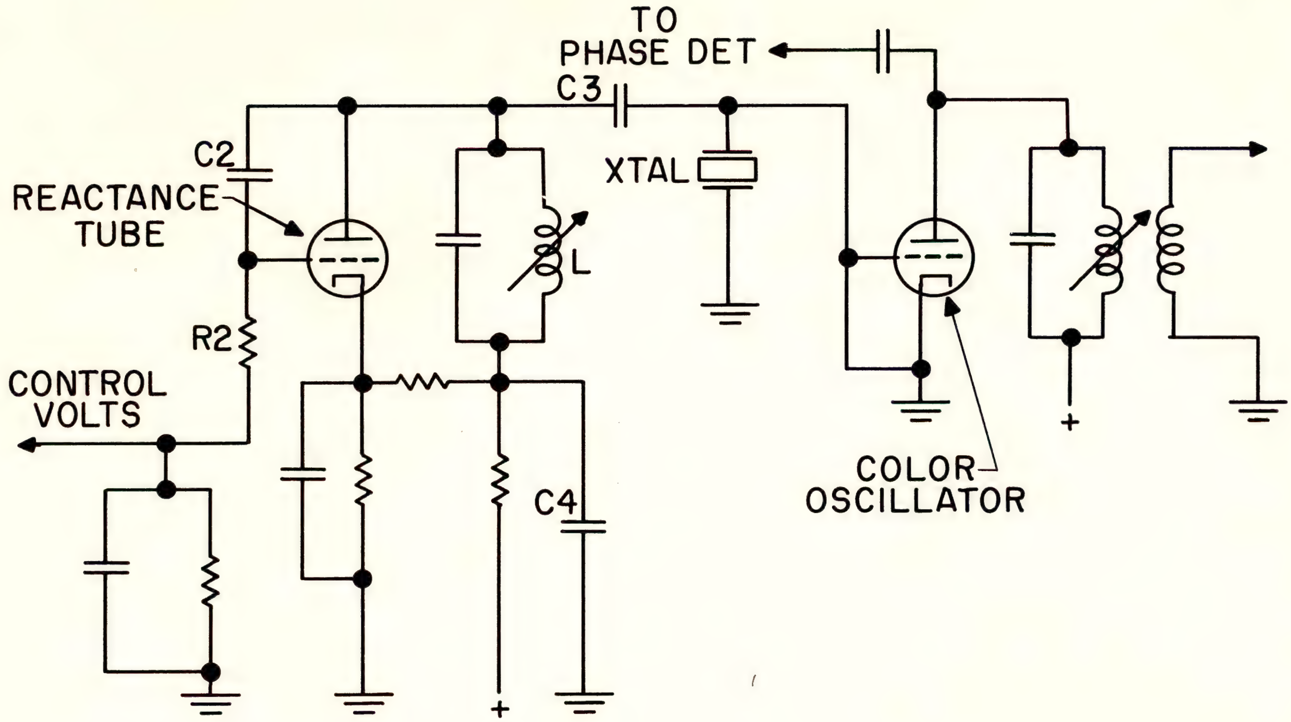


Figure 3-21. Reactance Tube & Color Oscillator

Reactance Stage

The reactance stage provides a means of locking the local 3.58 oscillator in exact frequency and phase with the transmitted color sync signal. The basic circuit is shown in Figure 3-21. Even though the local oscillator is crystal controlled, it must be locked in exact frequency and phase with the color sync signal. This is done by shunting the reactance circuit, which is an electronic capacitor, across the crystal. By varying the capacity across the crystal the frequency of oscillation can be varied.

A signal from the grid of the oscillator tube is fed to the plate of the reactance tube through capacitor C-3. C-2 connected from the plate of the reactance tube to the grid, is a large reactance as compared to the resistance of grid resistor R-2. A signal will appear on the grid of the reactance tube with the voltage leading approximately 90°. This leading voltage will cause a plate current in a reactance tube that leads the plate voltage by 90°. We now have a circuit that draws a leading current when a voltage is applied across it. This action is identical to the action of a capacitor, where the current leads the applied voltage by 90°.

A large capacitor will pass a large current and a small capacitor will pass less current when the same voltage is applied across both of them. The reactance tube can be made to look like a variable capacitor by varying the plate current through the tube. The correction voltage from the phase detector is connected to the grid of the reactance tube. This causes the plate current through the tube to change, and consequently, the apparent capacity to vary. Since the reactance circuit has a greater capacity potential than the crystal can tolerate, an inductance is connected from the reactance tube plate to AC ground. This inductance is adjusted so that the oscillator is in frequency and phase when the output of the phase detector is zero.

When a positive control voltage from the phase detector is applied to the grid, the reactance tube draws more current and appears to be a larger capacitor. By increasing the capacity across the crystal it will oscillate at a lower frequency. When the control voltage from the phase detector is a negative voltage, this will cause less plate current to flow in the reactance tube, acting like a smaller capacitor. A smaller capacity across the crystal will allow it to oscillate at a higher frequency. In order to maintain proper colors in our received color scene, it is necessary for the reactance tube to control the color oscillator to within a few degrees of one cycle.

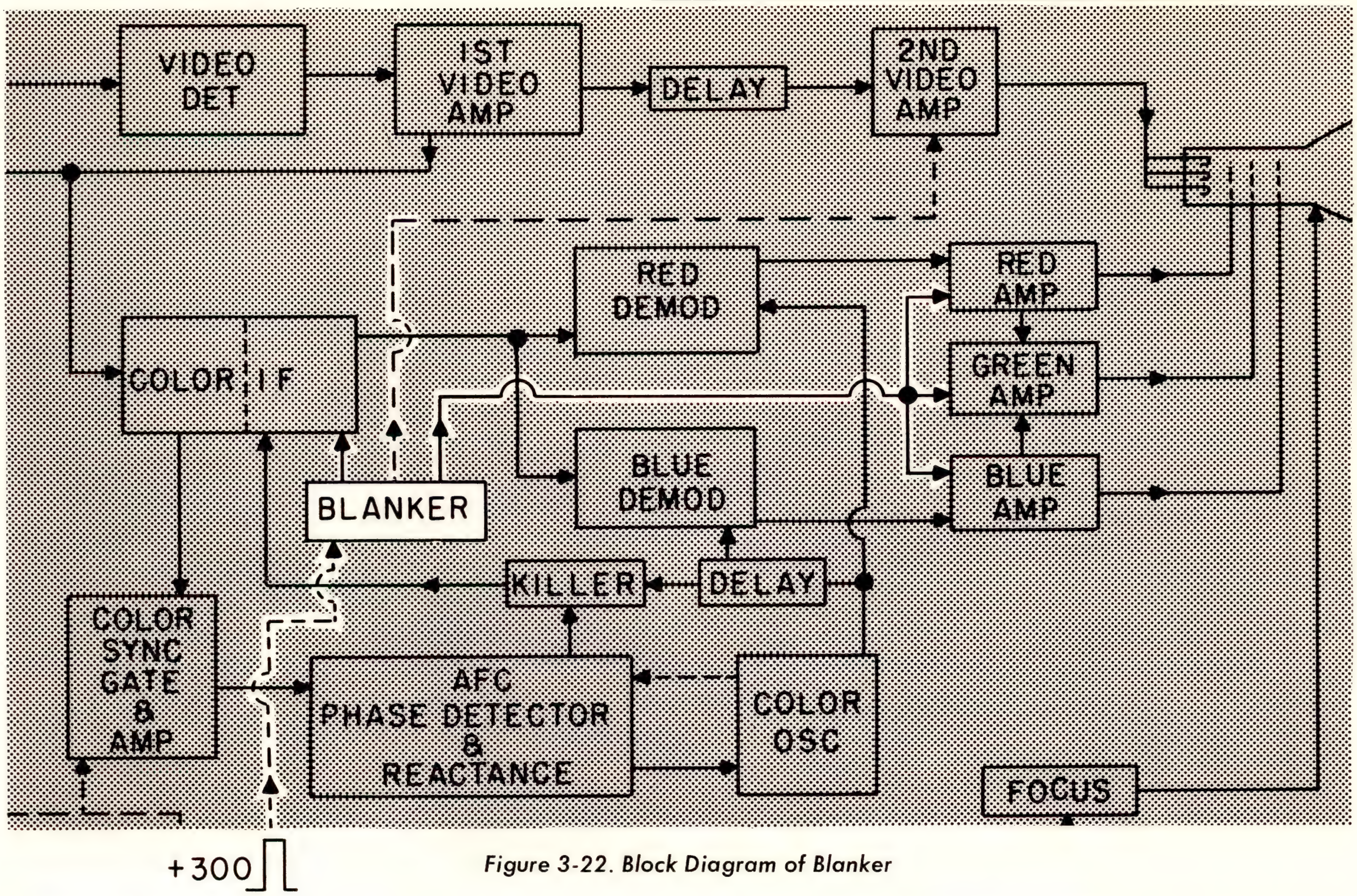


Figure 3-22. Block Diagram of Blanker

Blanker Circuit

The blanker circuit, shown in Figure 3-22, is used to accomplish three things. It blanks out the color synchronizing information to the demodulators during horizontal retrace; it is a phase inverter to provide a negative pulse for clamping the grids of the color amplifier at the start of each horizontal trace; and it provides a source of negative voltage for the brightness control in the second video amplifier stage.

Figure 3-23 shows a 300 volt peak pulse coupled to the grid of the blanker which drives this grid extremely positive during horizontal retrace. This causes a large current to flow from cathode to plate during this interval, producing a large positive pulse on the cathode. The cathode of the second color IF is connected to the cathode of the blanker which causes the color IF stage to be cut off during horizontal retrace. This allows the color signal, less color sync information, to the demodulators. If color sync were allowed to appear on the demodulators during retrace time, horizontal blanking would not be complete, allowing a veil-like condition on the screen.

Because of the high positive pulse on the grid of the blanker, grid current will flow through the grid resistor and approximately –70 volts DC will appear on the grid. This source of negative voltage is isolated and filtered, and connected to the bottom of the brightness control.

A negative pulse will appear in the plate of the blanker, since there is a 180° reversal from the signal on the grid. This is used to give clamping to the color difference amplifiers, which prevents raster color shift on the screen. The grids of all of the color difference amplifiers are capacity coupled to the previous stage and due to differences in signal and noise conditions, may gradually assume different grid voltages.

Let us assume, Figure 3-24, that we have the voltages indicated on the grids of the three color difference amplifiers at the end of one horizontal sweep. These differences in grid voltages will cause differences in plate current through the three color difference amplifiers, and consequently, a different grid potential on each of the color tube grids. If the plate voltages on these amplifiers were different than originally set up for a white raster, the screen would assume some color other than white.

The negative 9 volt pulse from the blanker is coupled to the cathodes of all three color difference amplifiers, which overcomes the 9 volt positive voltage normally on these cathodes during the active portion of the sweep. The cathode voltage of all of these tubes is now at zero potential, while the grids remain at the voltages indicated on the schematic. This is because the time constant of the .01 mf

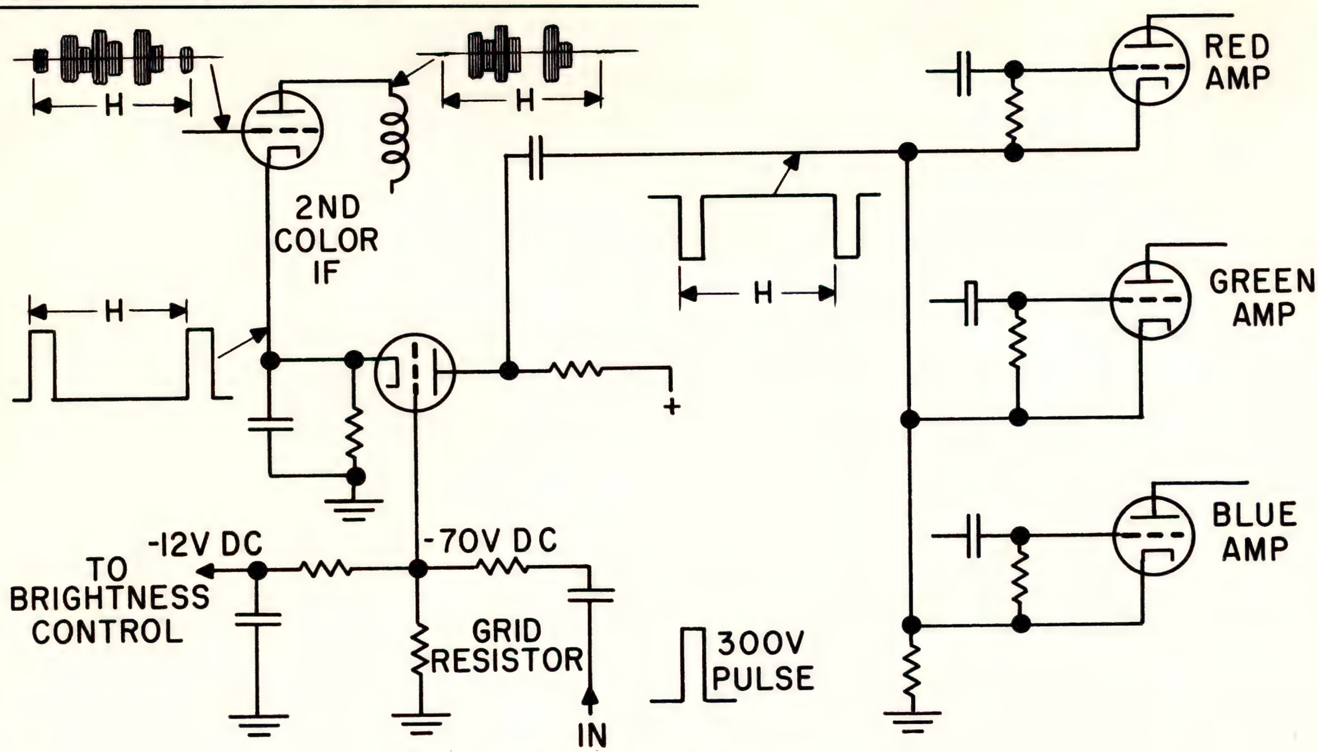


Figure 3-23. Blanker Circuit

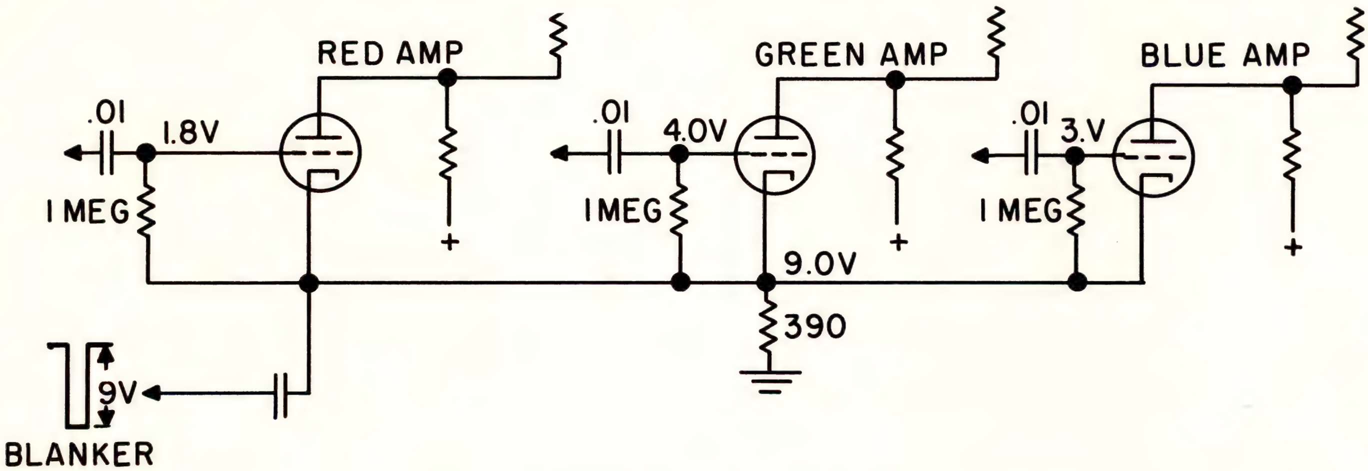


Figure 3-24. Clamping Color Difference Amplifier

capacitor and the 1 meg grid leak resistor is of too long a duration for the grid voltage to leak off to the cathode. The grids are now positive with respect to the cathode so electrons will flow from cathode to grid, dropping the grid voltage to the same potential as the cathodes. The time constant of the coupling capacitor and the grid resistor will maintain this grid voltage at that point for the start of the next sweep, and whatever AC voltages are coupled through the capacitors will fluctuate around this voltage axis. The cathode voltage will return to its average 9 volt level when the blanking pulse is removed and all three color difference amplifiers will start the trace with the same bias voltage on their grids.

The plates of these color difference amplifiers are connected directly to the grids of the picture tube, so by clamping the static current in these amplifiers, we can keep the plate voltages at a constant average level over varying input signal and noise conditions.

Color Killer Circuits

If the color IF amplifier is operating when the set is receiving a black and white signal, noise will develop in this circuit due to its operation at maximum gain with the absence of a subcarrier. The color killer circuit will automatically bias the second color IF amplifier stage into cutoff when a black and

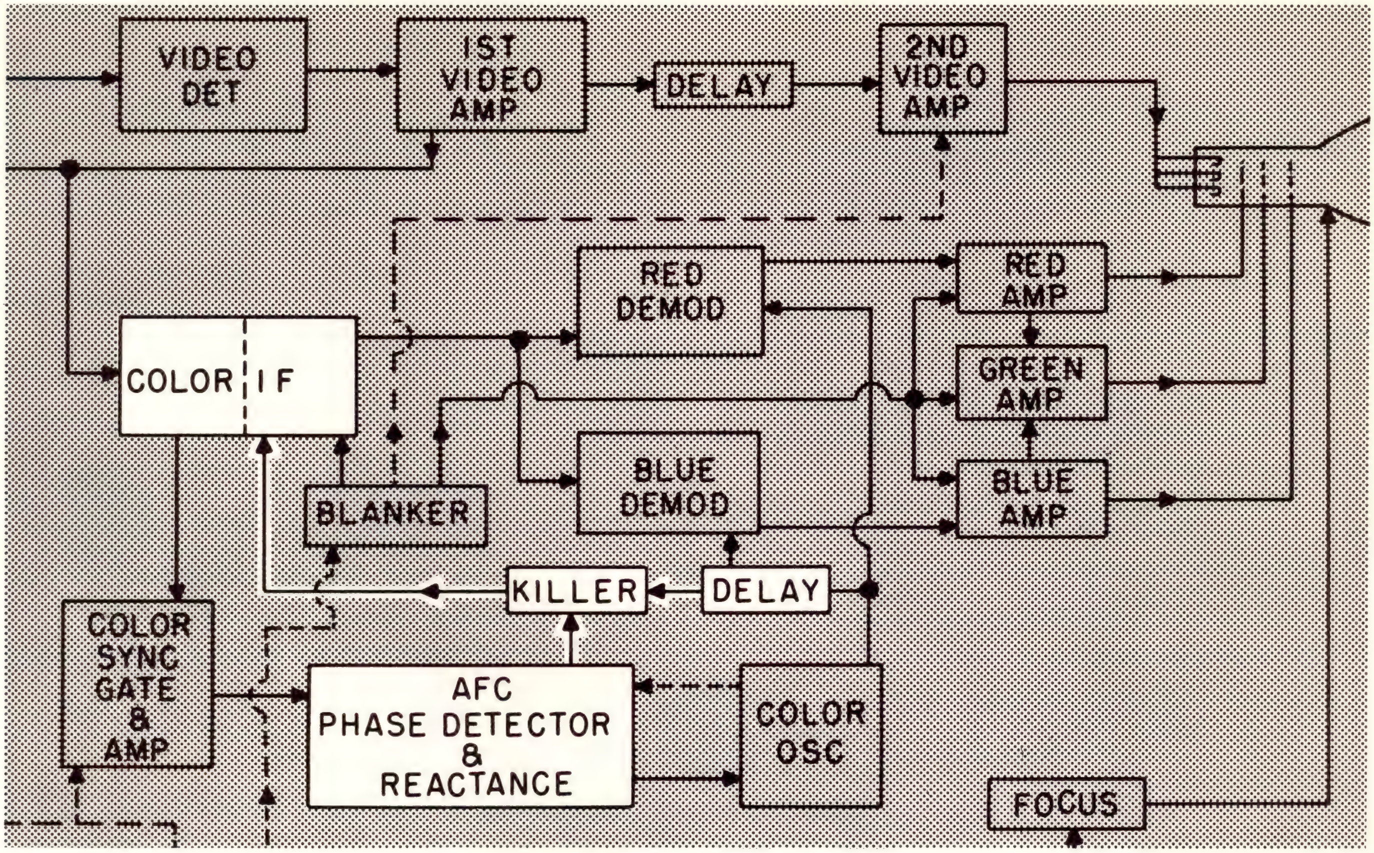


Figure 3-25. Block Diagram of Color Killer

white program is being received. Figure 3-25 shows the position of the color killer on the block diagram. When a color program is being received, this stage is biased for normal operation. Figure 3-26 shows the basic circuit.

This circuit is controlled by the presence or absence of color synchronizing information on the received signal. On the cathode of diode B in the color phase detector, color sync information will appear when transmitted. It will be in the 180° phase direction. The cathode of a germanium diode is attached to this point and its anode is connected through a filter network to the grid of the color killer control tube. A sample of the color oscillator signal of 0° phase is fed into the anode of the germanium detector.

The grid of the color killer tube is also connected to the arm of a threshold control, which allows us to set the cutoff point of the tube. A 300 volt positive pulse is injected through capacitor C-2 to the plate of the color killer tube. The plate of the color killer is connected to the grid return of the second color IF, through a filter network.

When we are tuned to a black and white transmission, only the color oscillator signal would be across the killer diode. This produces a negative 2 volts which is applied to the grid of the color killer tube. The threshold control connected from B+ to ground can be adjusted to overcome the negative 2 volts bias on the grid allowing the tube to **just** start conduction. With the color killer tube conducting, the positive pulse on the plate will cause a negative voltage to appear across resistor R-2, which is also part of a voltage divider from B+ to ground. The resultant voltage out of this network will be around 3.5 volts which, when compared to the 6.6 volts on the cathode of the second color IF tube, biases this tube to cutoff. This prevents any interference or circuit noise from getting through to the grids of the demodulators.

With the color transmission being received, the color sync signal appears on the cathode of the color phase detector. Since it is 180° out of phase with the color oscillator signal on the opposite side of the killer diode, it gives us twice the negative voltage output to the grid of the killer tube. This additional negative voltage on the grid of the killer tube now cuts the tube off, preventing any plate current flow. With the killer tube cut off, the 300 volt positive pulse on its plate does not cause any plate current to flow, so consequently there is no negative voltage developed across the resistor R-2. The top of resistor R-2 is also connected to a 27 meg resistor from B+ letting this point rise to approximately 6.5 volts and allows the second color IF tube to function normally. Color signals that come into the color IF will

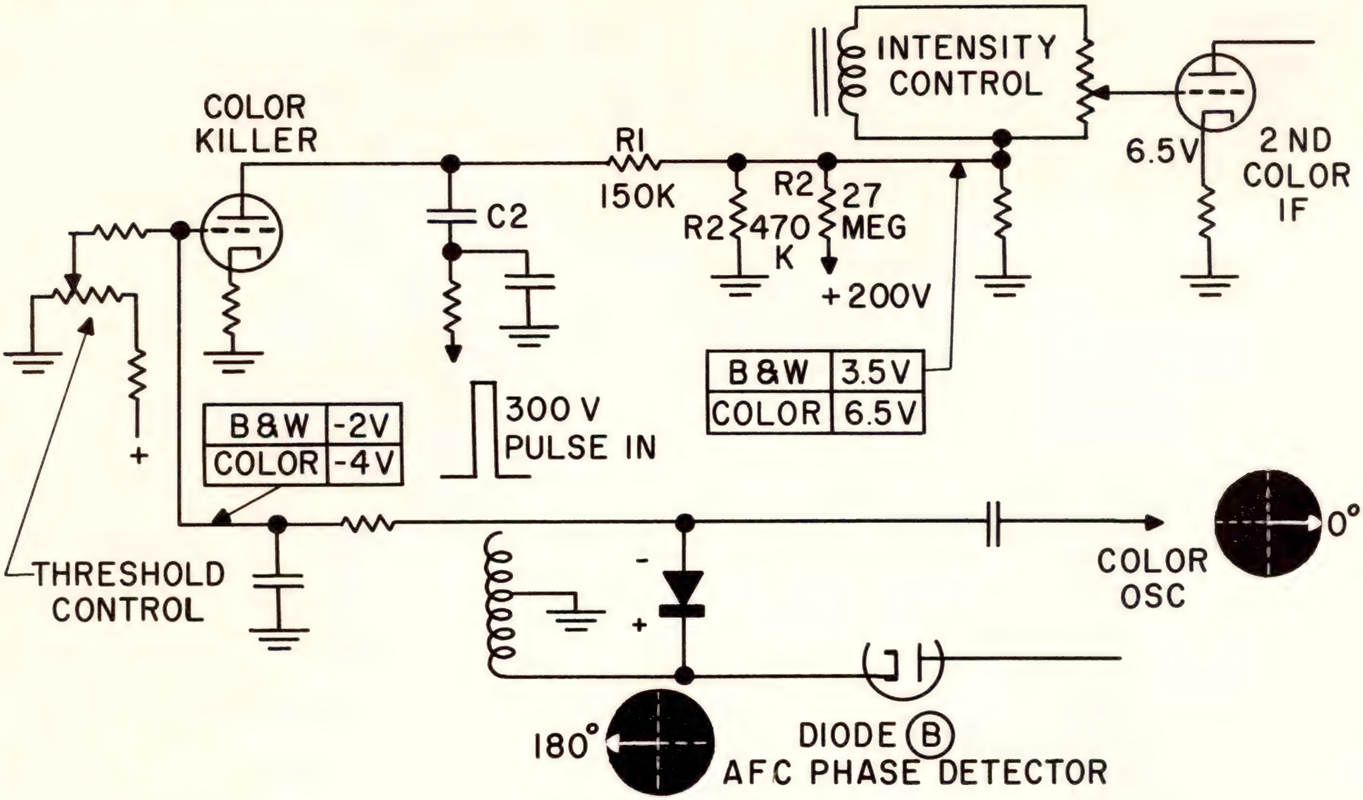


Figure 3-26. Color Killer Circuit

now go completely through to the grids of the demodulators.

Automatic Chroma Control (AGC)

A means is provided in most color receivers for controlling the gain of the color IF amplifiers, so that overload or wash-out will not occur as program content and signal strengths vary. Figure 3-27 shows the basic automatic chroma control circuit.

On the plate of the AFC phase detector diode A, there is developed a negative DC voltage which is proportional to the amplitude of the color sync appearing at that point. This voltage is filtered with a 1.8 meg resistor and connected to the bottom end of the first color IF input coil. The DC resistance of the coil is low, so this voltage appears on the grid as a bias voltage.

When a strong color signal is received, a large negative voltage will develop on the plate of AFC diode A. This voltage is applied to the grid of the first color IF causing the gain of the stage to be reduced. This brings the amplitude of the color signal down to a normal level. On a weak signal, the developed negative voltage will be less, allowing the color IF stage to increase its gain, bringing the amplitude of the color signal up to a normal level.

The color circuits just described may vary considerably in different sets, but the principles involved are the essential basis of the system. By understanding how the basic system works, it then becomes easy to understand the circuits with variations that will be found in commercially produced receivers.

The horizontal sweep circuit, the vertical sweep circuit, AGC circuits and sync separator circuits, are very similar to those found in standard black and white receivers and will not be discussed here. There are many splendid technical books available covering the operation of these circuits.

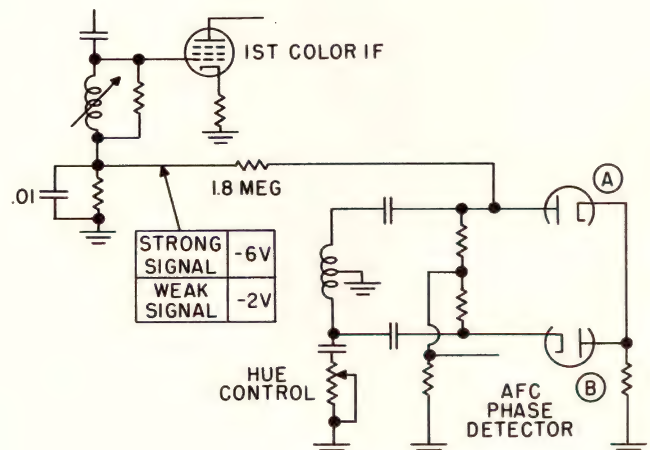


Figure 3-27. Automatic Chroma Control Circuit

4 / Color Cathode Ray Tube

Monochrome Cathode Ray Tube Operation

Figure 4-1 shows a cross section of a black and white picture tube.

When the cathode of the electron gun is heated, a stream of electrons are emitted and attracted toward the front of the picture tube. The arrangement of the electron gun is shown in Figure 4-2.

The potential difference between the control grid and the cathode determines the amount of beam current and consequently, the brightness of the tube. The screen grid has a positive potential applied and accelerates the electron beam into the focus element.

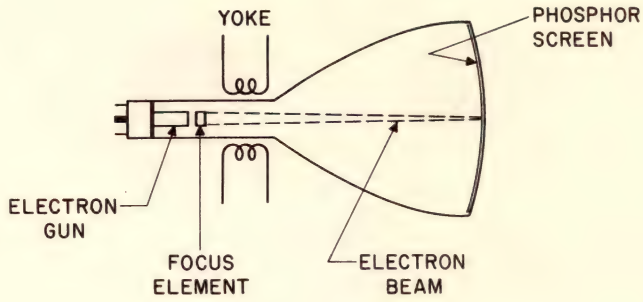


Figure 4-1. Cross Section View of Black & White Picture tube

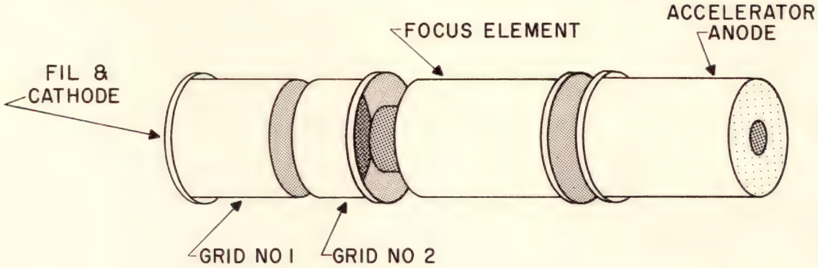


Figure 4-2. Electron Gun Assembly

The voltage applied to the focus element is positive and is usually adjustable. The focus element forms the stream of electrons so that it is concentrated on a small spot when it strikes the phosphor screen. The accelerating anode increases their velocity and provides sufficient energy to fully illuminate the phosphor screen.

The beam of electrons is caused to scan the tube screen by means of an externally mounted deflection yoke. As current flows through the coils, magnetic fields are produced within the neck of the tube, and the electron beam, passing through this field, is deflected in both a vertical and a horizontal direction to produce a raster.

The Tri-Gun Color Cathode Ray Tube

The color cathode ray tube as used in Motorola receivers has three electron-gun assemblies. Figure 4-3 shows the complete assembly.

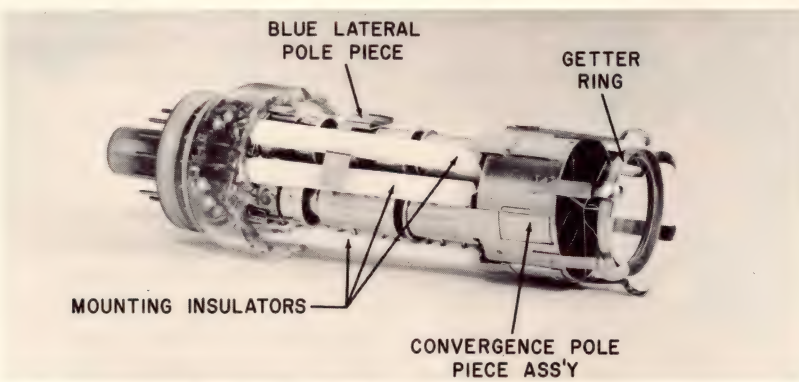


Figure 4-3. Three Electron Gun Assembly

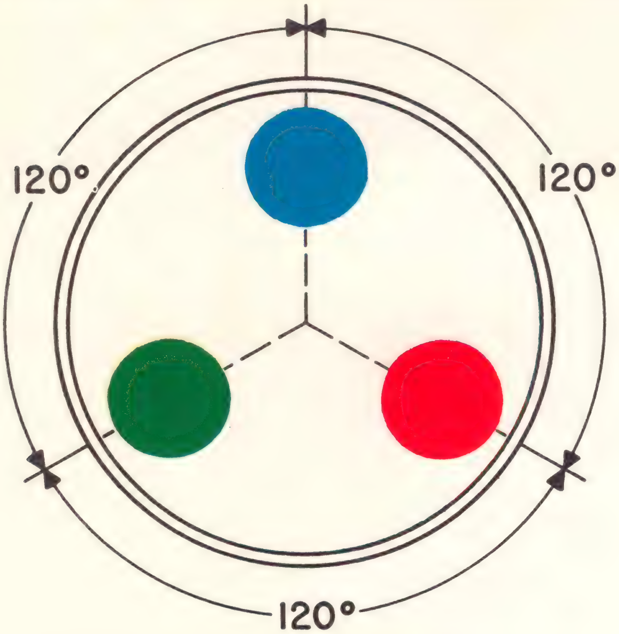


Figure 4-4. Relative Position of Three Electron Guns

Each gun in the three gun assembly is quite similar to the electron gun used in a black and white picture tube. The three guns are arranged 120° apart around the center axis of the tube. Figure 4-4 shows the relative position of each of the three guns.

When viewing the electron gun assembly from the rear or socket end, the blue gun will be on top and the red and green guns are as shown in Figure 4-4. The three guns are not mounted parallel to each other but are tilted slightly toward the center axis of the tube, so that all three guns are aimed at a spot at the center of the screen.

The Shadow Mask and Phosphor Dot Screen Assembly

The screen of a tri-gun color tube is considerably different from the phosphor screen in a black and white tube. Instead of a single phosphor coating on the face of the tube, three different phosphors capable of emitting three different colors of light, are used. The three phosphors are arranged as a series of dots. Directly behind the faceplate is a shadow mask which contains one hole for each three phosphor dots on the faceplate. The streams of electrons from the guns must pass through the holes in the shadow mask in order to strike the phosphor material and produce light.

Function of the Shadow Mask

The three electron beams must be controlled so that each beam strikes only the phosphor dots of one color. The shadow mask makes this possible. The individual dots of phosphor material are placed on the faceplate of the picture tube as shown in Figure 4-5.

The three dots are arranged in a triangular pattern and the group is known as a triad. The triads, or groups of three dots, cover the entire faceplate. The shadow mask contains about 500,000 holes with one hole behind each triad. The mask is positioned so that each hole is located dierctly in front of the center of a triad. Figure 4-6 shows the relative position of the shadow mask to the phosphor triads.

Each opening in the shadow mask is directly over the center of each triad. When viewed from a point perpendicular to any individual hole in the mask, we see a small portion of each color phosphor. However, the three guns do not have the same exact point of origin so the electron beams will approach the mask from three different angles, none of which are perpendicular to the hole. If the approach angles are correct, each electron beam will strike only the proper color. This principle is demonstrated in Figure 4-7.

An explanation of how the color phosphors are

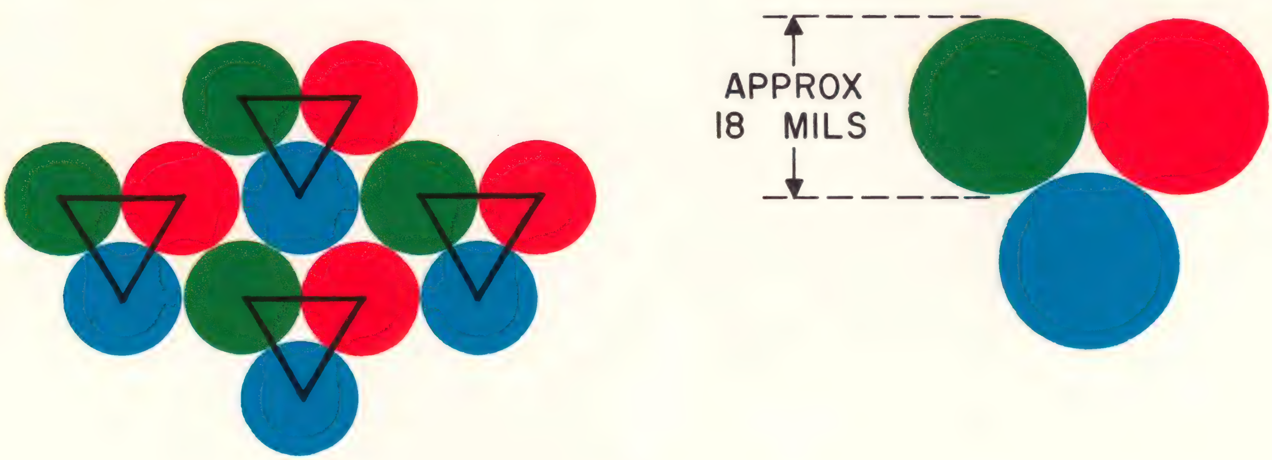


Figure 4-5. Phosphor Triads As Viewed From Front of Tube

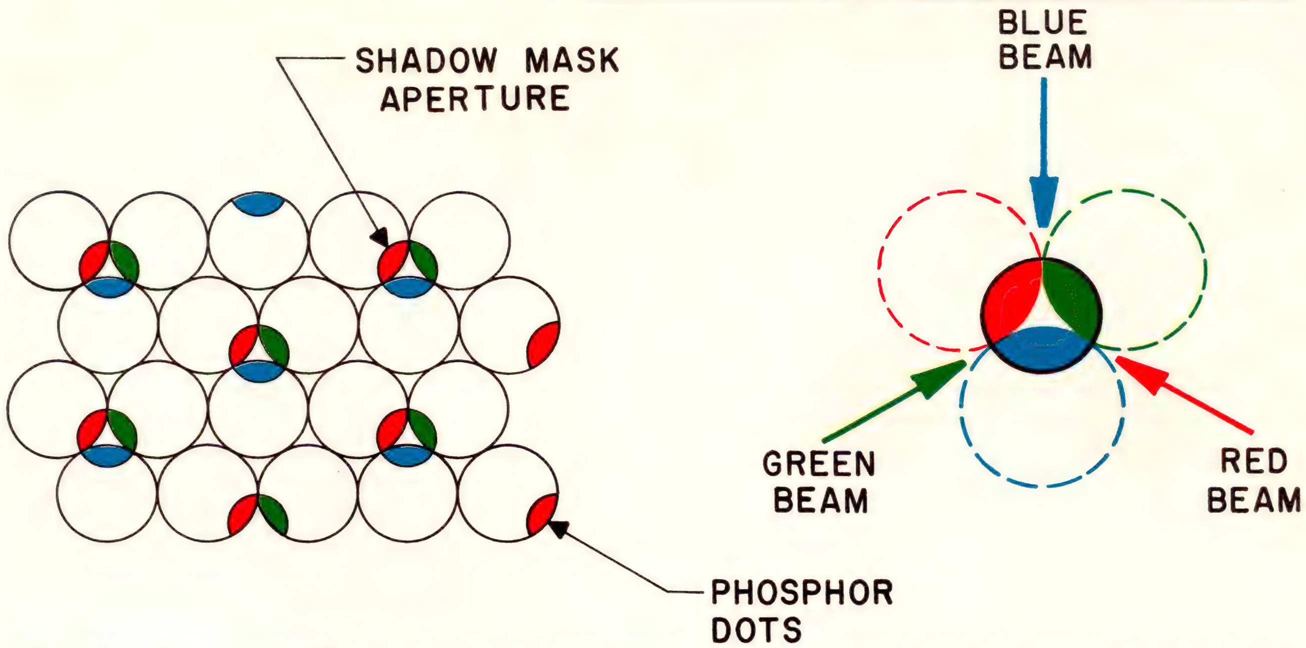


Figure 4-6. Relative Placement of Shadow Mask to Phosphor Screen as Viewed from the Center of the Tube Neck

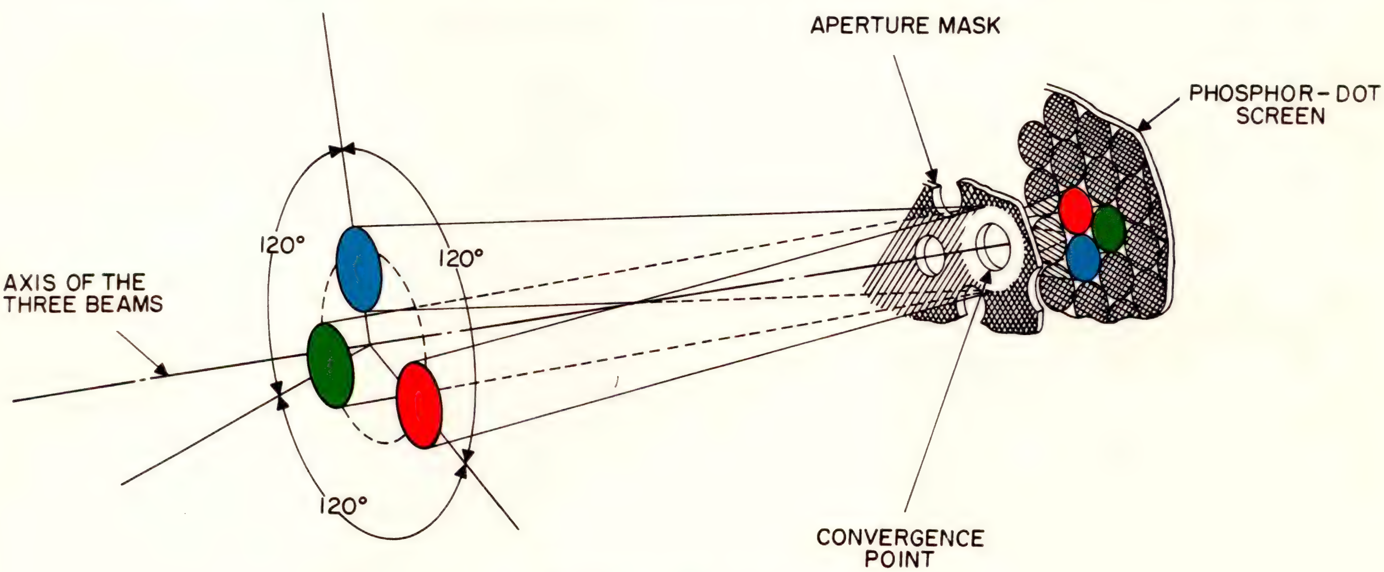


Figure 4-7. Alignment of Guns, Mask and Phosphor Dots

placed on the faceplate will lend to the understanding of the shadow mask principle. Initially, a faceplate and shadow mask are selected. The mask is mounted into the faceplate in such a manner that it can be removed and later re-installed in exactly the same position. The same faceplate and mask will remain together during the manufacturing process.

The faceplate is covered with an even coating of photo sensitive green phosphor material. The shadow mask is then placed accurately in the faceplate and placed in a special jig. A point size light source is placed in the position the green gun would be positioned in the tube, and floods the whole shadow mask with light. When the light shines through the holes in the shadow mask and hits the phosphor coating, the phosphor material will become hardened and will stick to the glass. The faceplate is then sprayed with water, removing the phosphor that was not exposed to light, leaving the exposed wafers of phosphor material adhering to the glass.

An even coating of photo-sensitive blue phosphor material is then put over the faceplate, including the hardened green phosphor wafers. The shadow mask is accurately put back into position and the light source is moved to the position the blue gun will occupy in the finished tube. This will harden the blue phosphor coating where the light strikes it, which will be just adjacent to the green phosphor dots which are already present.

At the completion of the exposure, the faceplate

is again washed, removing the unexposed blue phosphor material, leaving blue phosphor wafers where the light source had hardened them.

Finally, the faceplate is again coated with a photo-sensitive red phosphor material and the shadow mask again accurately positioned. The light source is now moved to the position that the red gun will occupy in the tube and shines through the shadow mask holes, causing red phosphor wafers to be exposed and hardened.

The shadow mask is then removed again and the unexposed red phosphor material is washed away. We now have a precise arrangement of the three color phosphor dots in front of the shadow mask which will be sealed into the finished tube.

After the phosphors for each of the three colors are deposited, we can alternately place our eye at the point where each gun will be located in the finished tube and will see phosphors of only one color. The color of the phosphor that is seen will depend on which of the three gun positions the eye occupies.

Since we have controlled the position of the light source that exposed the individual dots, we can install the electron guns in the same positions and each gun will strike phosphor dots of one color.

Control of the Electron Beams

A black and white picture tube requires a deflection system with provisions for centering and focus controls to provide control of the electron beam. The three gun color picture tube requires these controls, plus additional control elements which will be discussed.

Color Purity

In order for the color picture tube to correctly reproduce color pictures, the individual electron beams must light phosphors of only one color. Each electron beam is then capable of producing a pure field of either red, blue, or green.

In order for each beam to light only the proper phosphor, it is of extreme importance that the approach angle of the electron beams to the shadow mask be correct. The correct angle is the one that duplicates the trajectory of the light source that formed the dots. An incorrect approach angle will result in an electron beam lighting phosphors other than the correct color. With this condition, the tube would be incapable of reproducing pure colors. Figure 4-8 shows the effect of an improper approach angle.

Each individual electron beam is only partially hitting the correct phosphors. The remaining portion of the beam strikes other phosphors of the wrong color. In Figure 4-8, the electron beams are too high and are not centered on the triad. The arrows indicate the direction of travel needed for correction.

Adjustment of Color Purity

It is not always possible to place the electron guns in the tube accurately enough, in relation to the shadow mask, to always have a perfect approach angle. Therefore, some means must be provided to correct any approach angle error of the electron beam. The corrective action must be made before the three beams pass through the shadow mask.

An electron stream passing through a magnetic field will be deflected at right angles to the field. The amount of deflection will depend on the strength of the field. By placing a magnet that has adjustable strength and direction of field on the neck of the tube, we can control the approach angle of the electron beams to the mask.

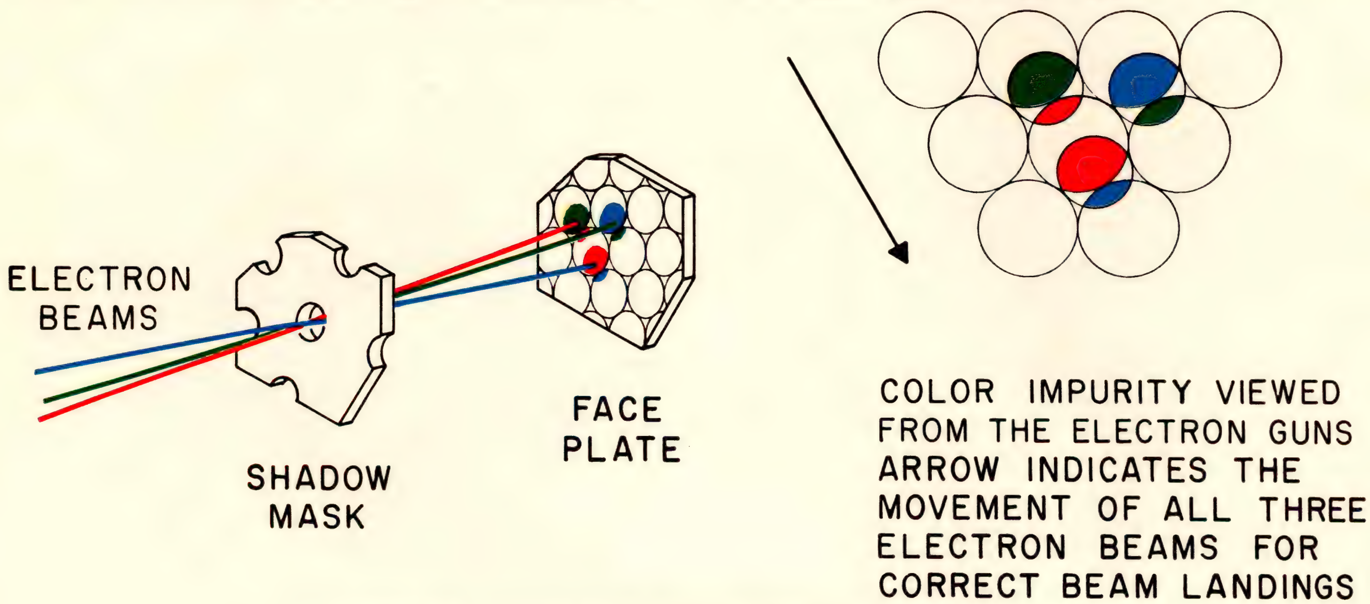


Figure 4-8. Cause of Color Impurity (Improper Beam Landings)

A color purity device, that supplies the proper field, is shown in Figure 4-9.

The purity magnet assembly consists of two similar ring magnets. Each magnet has a square and a round tab. The square tab in Magnet A is the north pole while the round tab in Magnet B is the north pole. When the magnets are assembled with like tabs together as shown in C, the two fields will cancel, since the two magnetic fields are in opposition. The purity device magnets may be moved independently or both may be rotated together. Figure 4-10 shows the action of the purity device as it is adjusted.

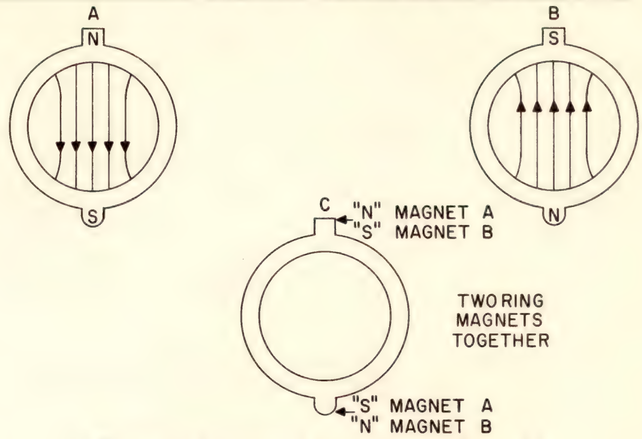


Figure 4-9. Color Purity Magnet Assembly

Figure 4-10:A shows the purity device with the tabs together. With the tabs so adjusted, there will be no movement of the three electron beams. They will pass through the device as if it were not present.

Figure 4-10:B shows the tabs separated so that a magnetic field is produced. The electron beams passing through the purity device will be deflected at right angles to the flux lines, so beam movement will be in the direction indicated by the arrow. Notice all three beams move in the same direction by the same amount.

Figure 4-10:C shows the same tab spacing, but the entire assembly has been rotated 120°. Since the tab spacing has remained constant, the strength of the field is the same as in 4-10:B. The device has been rotated so the direction of the flux lines has changed and the beams will be deflected in the direction indicated by the arrow.

Figure 4-10:D has the same flux direction as 4-10:C, but has the tabs open to produce a stronger field. The deflection direction is the same, but the beams have been deflected a greater amount by the stronger field. By adjusting the tab opening, we can adjust the amount of beam deflection and by rotating the assembly, we can adjust the direction that the beams are deflected. Thereby, we can posi-

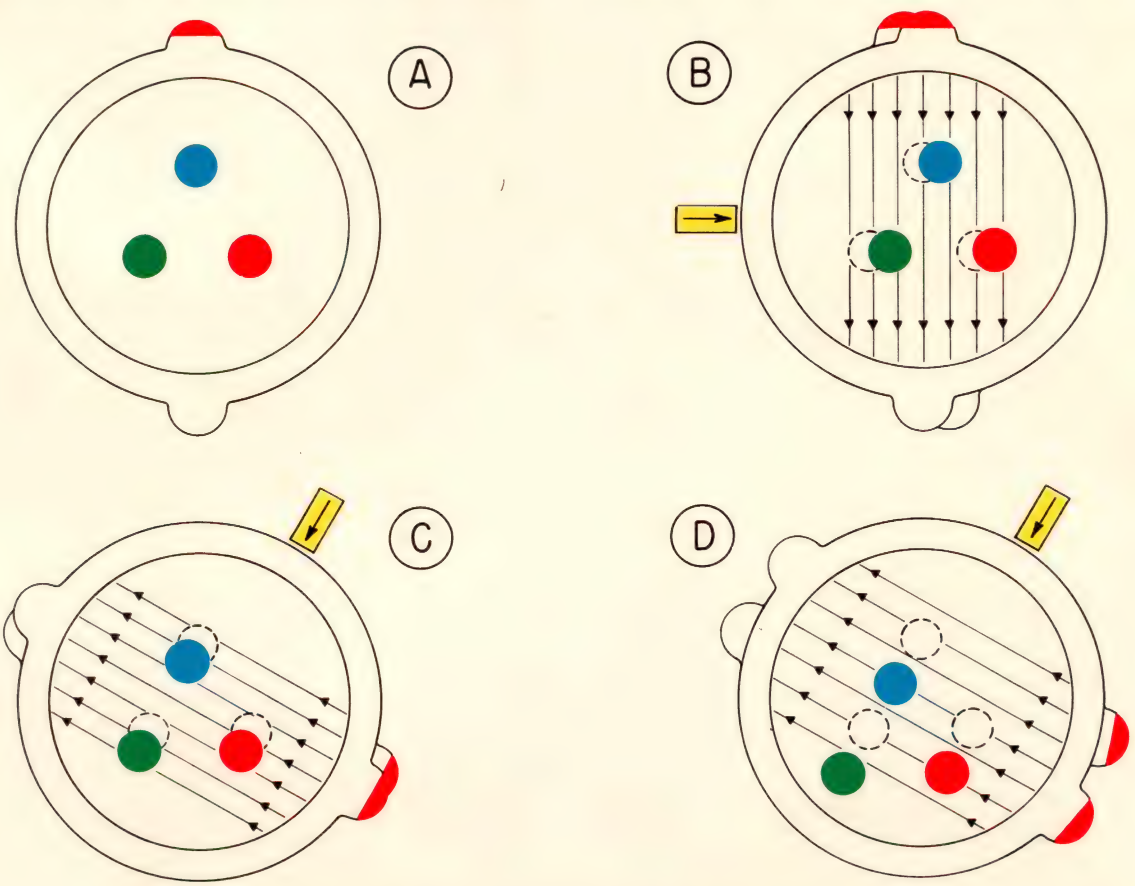


Figure 4-10. Beam Movements and Purity Adjustments

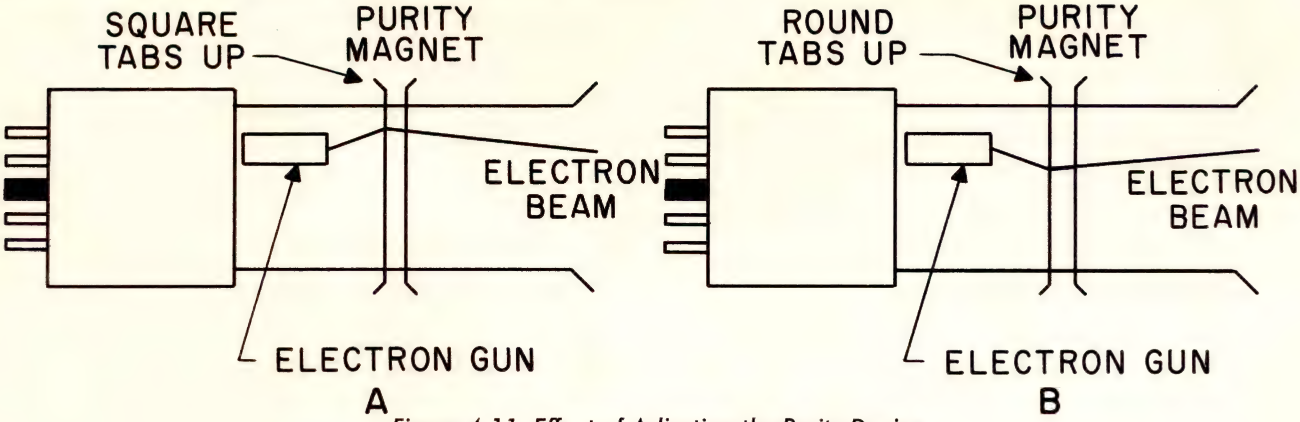


Figure 4-11. Effect of Adjusting the Purity Device

tion the three beams in the tube neck, so that they approach the shadow mask at the proper angle or appear to originate from the same point as the original light source used to place the phosphors on the screen.

The purity device is usually located around the neck of the picture tube before the beams are deflected by the yoke. Figure 4-11 shows a side view of how adjustment of the purity device can change the apparent point of origin of the three electron beams.

Figure 4-11:A shows the purity device with the tabs open and the direction of its field such that the three beams will be deflected upward and in 4-11:B the device is rotated 180° so the three beams are deflected downward. The magnetic purity device is adjusted to produce pure fields as viewed at the center of the screen.

For outer areas of the screen, it is important that the electrical center or deflection center of the yoke be correctly located, in order to maintain the proper approach angle to the screen. Purity adjustments for areas outside the center of the screen are made by sliding the yoke along the neck of the tube.

Shown in Figure 4-12 is the effect of mounting the yoke with the deflection center located properly and a second position located too far to the rear. When the deflection center is correct, the electron beams will leave the yoke field, pass through an

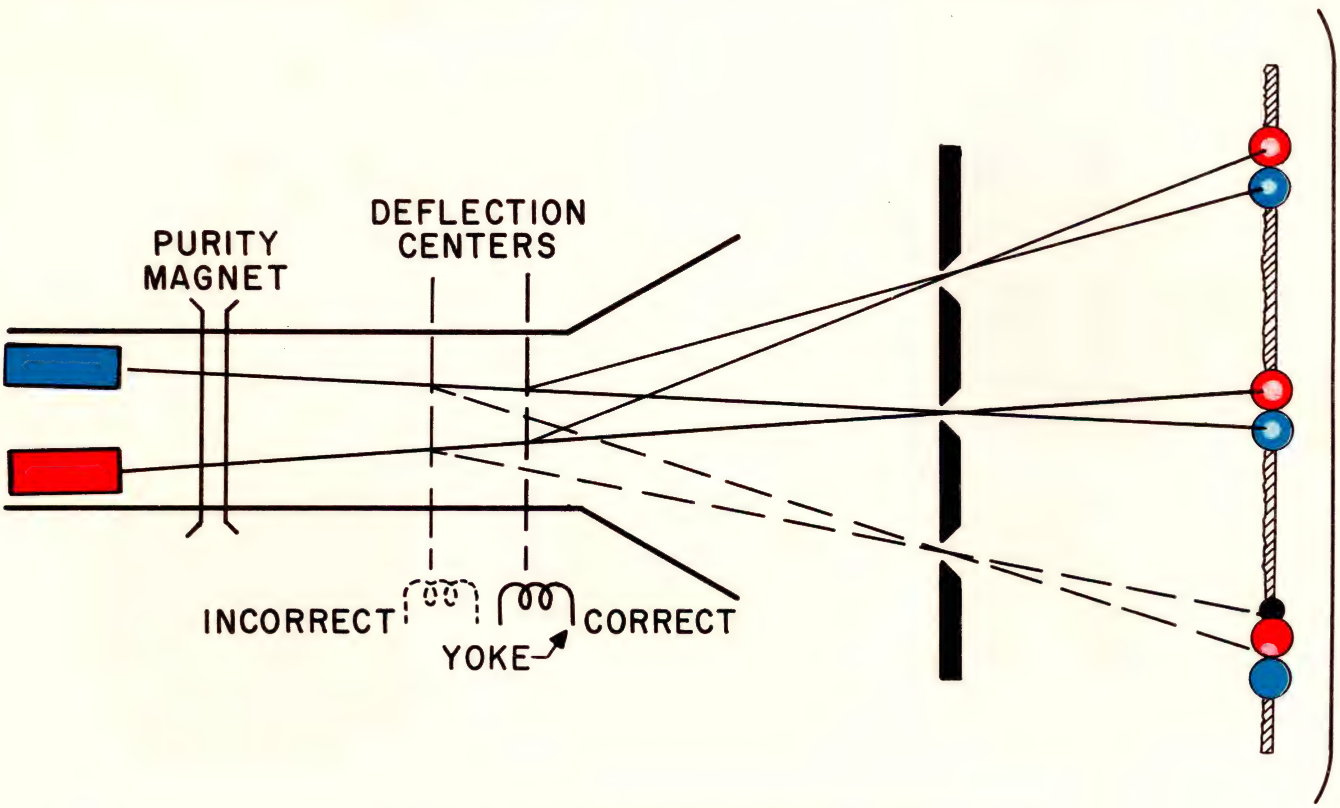


Figure 4-12. Effect of Moving Yoke Deflection Center

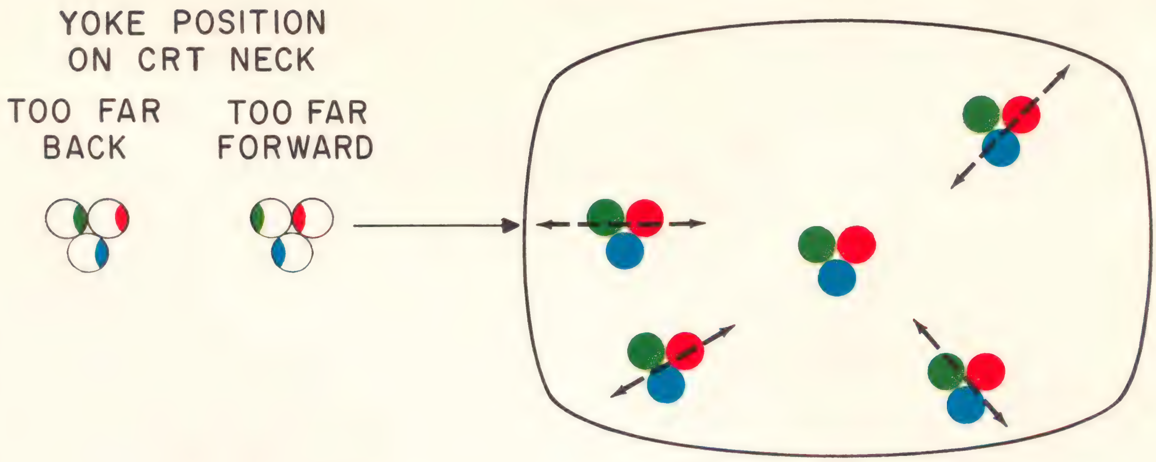


Figure 4-13. Effect of Moving Yoke on Neck of Color Tube

opening in the shadow mask, and illuminate the correct phosphors (top of Figure 4-12). If the yoke is moved toward the rear of the tube neck (moving from the correct deflection center), the electron beams passing through the corresponding hole at the bottom of the mask will now do so at a different angle and will miss the correct phosphors as indicated in the figure.

Figure 4-13 shows the direction of movement of beam landing as the yoke is moved forward and backward.

As the yoke is moved along the neck of the color tube, the impact point will move along the lines drawn through the triads shown in Figure 4-13. Notice that the area at the center of the screen does not change as the yoke is moved. See Fig. 4-14.

Purity adjustments are started with the yoke moved as far to the rear as possible. The magnetic purity device is adjusted for correct strength and polarity to produce a pure field at the center of the tube. The green and blue guns are turned off, using the screen grid controls for these adjustments, and only the red gun is left operating. The red field is used because the red phosphors are the least efficient and impurity can be seen more easily. If the beam is partially hitting another color phosphor, its more efficient light output would make the error readily apparent. After the purity device is adjusted to produce a pure red field at the center of the screen, the yoke is slowly moved forward, until a pure red field is produced at the edges of the screen. The green and blue fields are then individually checked for purity by turning down the red screen control and turning on the other two screen controls in turn.

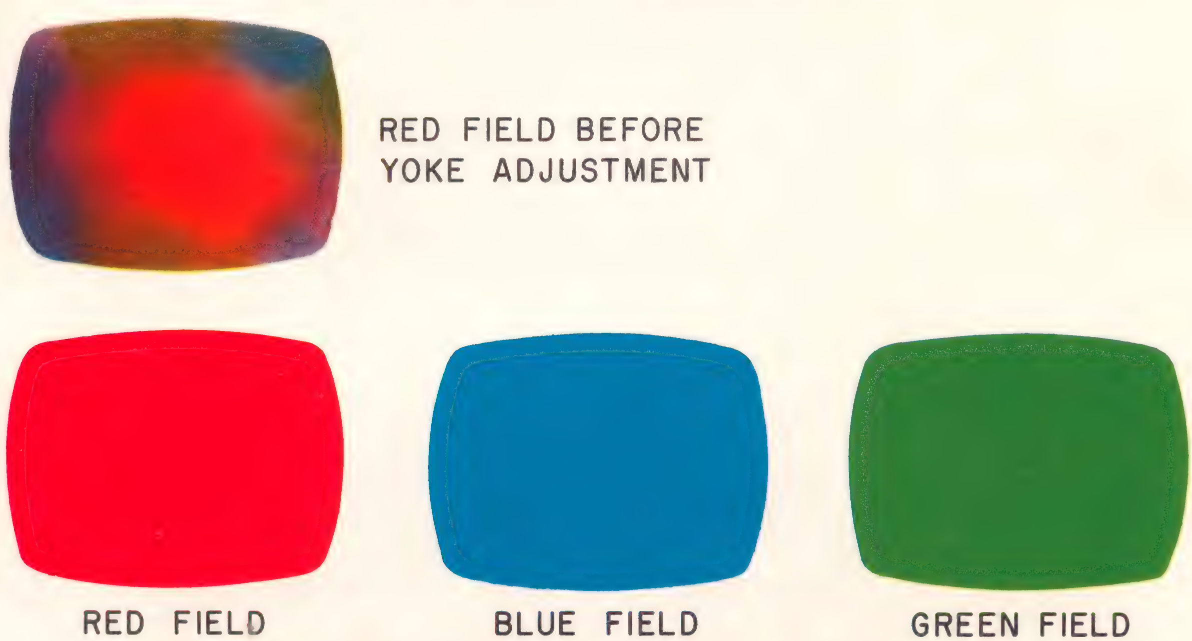


Figure 4-14. Individual Fields After Purity Adjustment

5 / Convergence

Static Convergence

It is not only necessary that three pure rasters be produced. They must also be superimposed on one another, at all points on the screen. When the three electron beams, coming from the guns, are positioned in relation to each other so that they cross over at the plane of the aperture mask, the beams are said to be converged. When this condition is satisfied, each of the three electron beams produce a raster and the three rasters will be superimposed at all points and are said to be converged.

A cross-hatch or dot pattern produced by a generator is used to determine if the three rasters are superimposed or converged at all points. The generated cross-hatch pattern turns all three electron beams "on" for a short interval, several times, as the set is scanned vertically and horizontally. If the three rasters are superimposed at all points, the areas where all three beams are turned on will appear as superimposed vertical and horizontal white lines. If the rasters are not superimposed, red, blue or green vertical and horizontal lines will be seen.

The three electron guns in the color tube are physically aimed at the same spot on the screen, so the three rasters are nearly superimposed or converged at the center of the screen. To allow for slight production variations of the tube, individual beam aiming adjustments are provided so that the three rasters may be exactly converged or superimposed at the center of the screen. The beam aiming device is called a "convergence magnet assembly" and is shown in Figure 5-1.

The convergence magnet assembly consists of a horseshoe ferrite core, on top of which is placed a ceramic disc permanent magnet. The way this magnet is polarized is indicated by the letters "S" and "N". There are also two coils of wire wound on the horseshoe core, but we will not be concerned with them at this moment, since we are only interested in convergence at the center of the screen.

Figure 5-2 shows how this convergence magnet assembly is placed on the tube. Only one is shown here in this illustration, but one such device is placed over each of the three guns.

The gun structure inside the tube is constructed

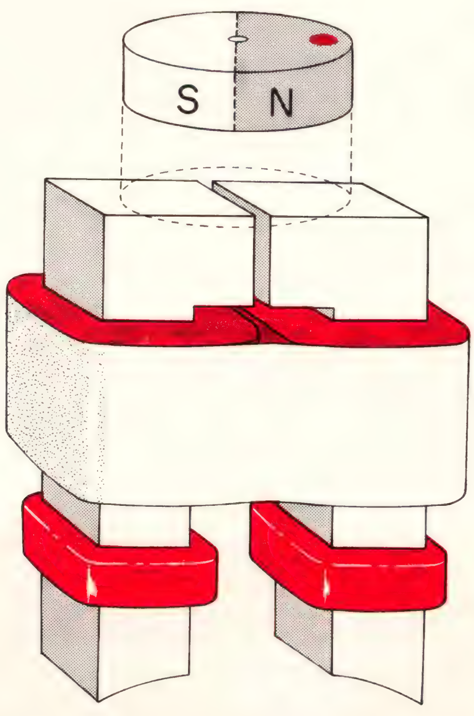


Figure 5-1. Convergence Magnet Assembly

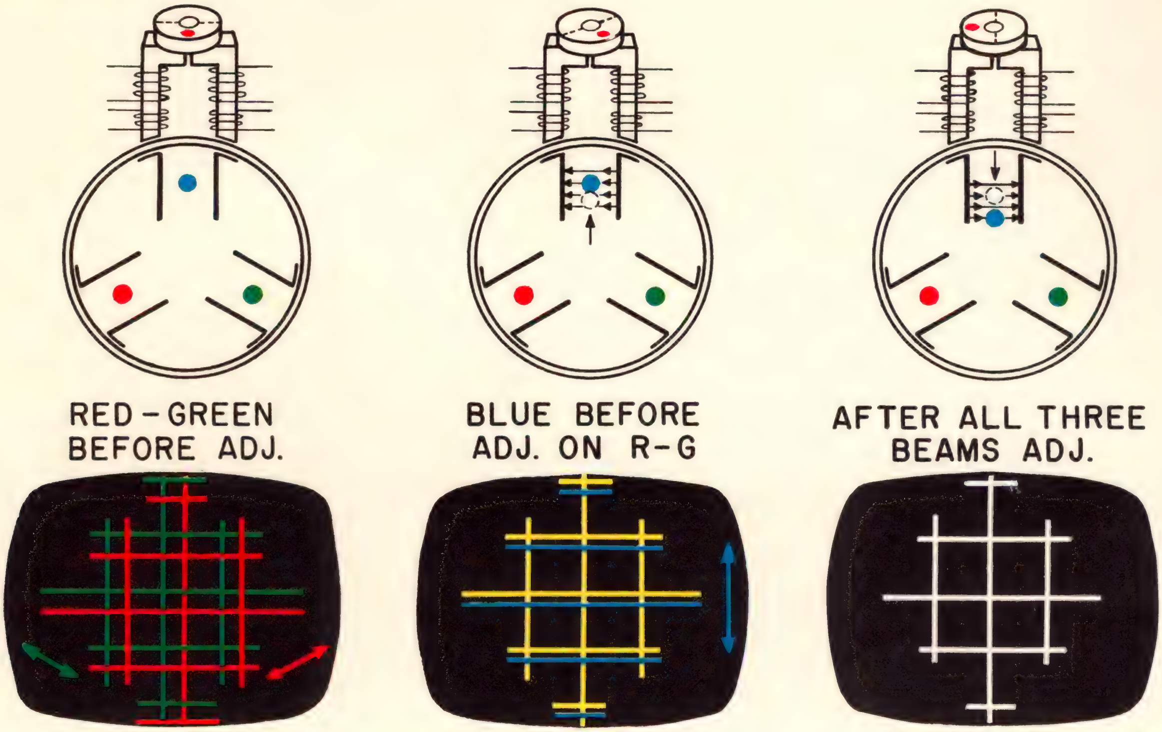


Figure 5-2. Effect of Static Convergence Magnet

so that the electron beam will have to pass between two pole pieces that correspond to the spacing of the ferrite core of the convergence magnet assembly. The illustration on the left (Figure 5-2) indicates this arrangement, with the permanent disc magnet turned, so that there will be no field across the ends of the core.

The center illustration (Figure 5-2) shows the magnetic field that is set up in the gun pole pieces when the magnet is turned slightly toward one direction. The magnetic lines of force traveling toward the left will cause the raster to be deflected upward and seek a new position on the face of the picture tube.

The illustration on the right (Figure 5-2) shows the disc magnet turned in the opposite direction causing the magnetic field to travel toward the right, displacing the raster in the opposite direction.

By using three of these convergence magnet assemblies, we can individually control the radial position of the three rasters on the face of the tube. But again, because of the mechanical limitations, we may have to move the blue beam in a lateral direction in order to make sure that all three beams hit at the same point on the face of the tube.

To provide this adjustment, an additional pole piece is constructed into the blue gun assembly; this is shown in Figure 5-3.

This is called the "Blue Lateral Magnet". It is a long cylindrical ceramic magnet that is polarized as indicated in the left-hand illustration. As seen here, when the magnetic field goes in one direction, the beam is deflected laterally toward one side of the tube and when the magnetic field is reversed, the beam is deflected to the other side of the tube. The change of direction of the magnetic field is accomplished by rotating the blue lateral magnet around its own axis. The internal pole piece in the neck of the tube minimizes interaction with the red and green beams.

In some cases, the blue lateral magnet may be located on the side of the tube neck rather than on top as shown in Figure 5-3. Adjustment of the magnet with the device located on the side of the neck will cause red-green and blue to move in opposite directions. This double action will allow blue to be converged with a minimum amount of magnetic strength and will, in some cases, minimize purity change with the adjustment of the blue lateral magnet.

We have now provided the necessary external adjustments on the three beams of the tube to make it do what it was originally designed to do. The purity magnet adjusts the proper approach angle of all three beams to the shadow mask, so they will each see the proper color phosphor. The static convergence magnets position each of the three beams individually for a radial position in the tube and the blue lateral magnet gives the blue beam an additional correction in a lateral direction. With these adjustments, all three beams will hit the same spot at the center of the screen at the same instant.

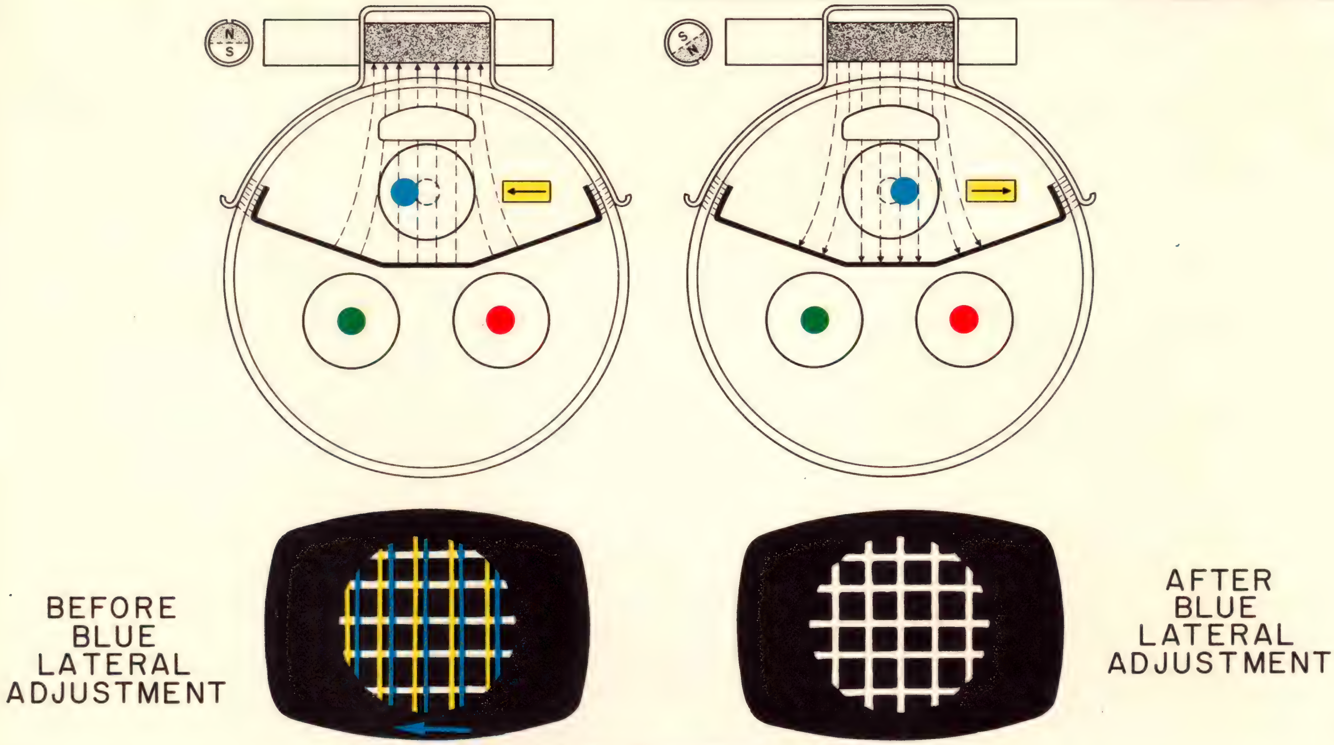


Figure 5-3. Lateral Movement of Blue Beam

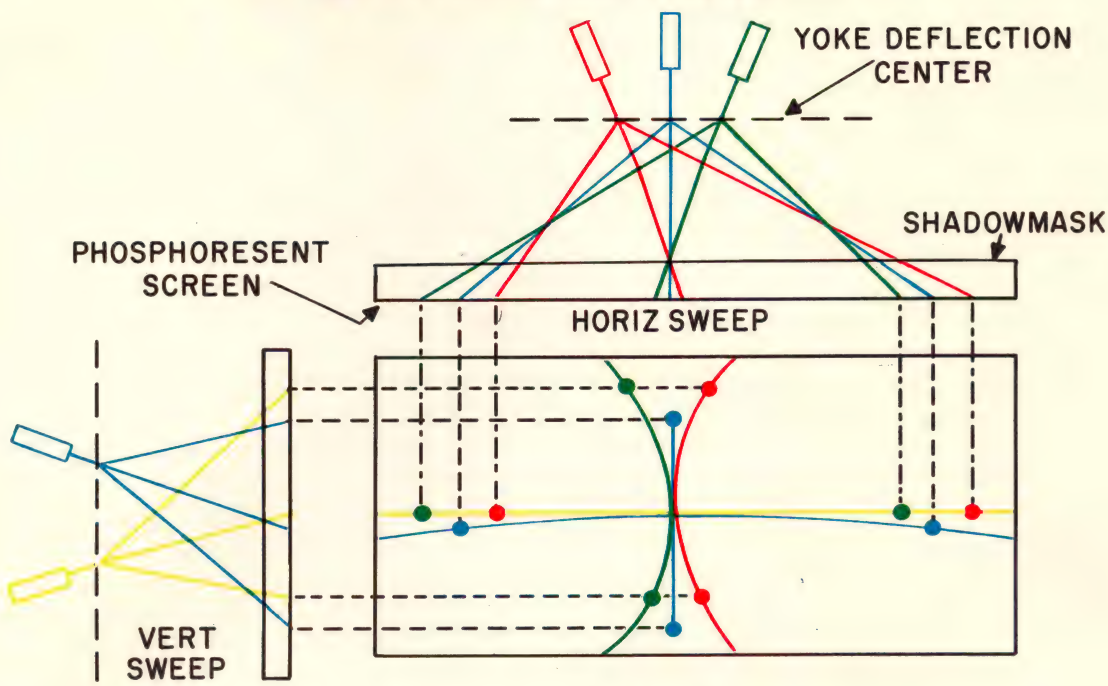


Figure 5-4. Misconvergence Caused by CRT Geometry

All of these adjustments are known as "Static Adjustments" and are adjusted while viewing the center of the screen.

Other corrections have to be made with the three beams as they sweep to the outer edges of the screen, and these are known as "Dynamic Convergence Corrections".

Dynamic Convergence

In the preceding section, we have discussed the controls necessary to converge the three electron beams at the center of the screen. In addition to these controls, other corrections are necessary to insure that all three beams remain converged at all areas of the screen.

Figure 5-4 shows the misconvergence caused by the picture tube geometry. The three rasters are made to converge at the center of the screen by adjusting the static magnets. Since the three rasters are projected on the nearly flat faceplate, the dis-

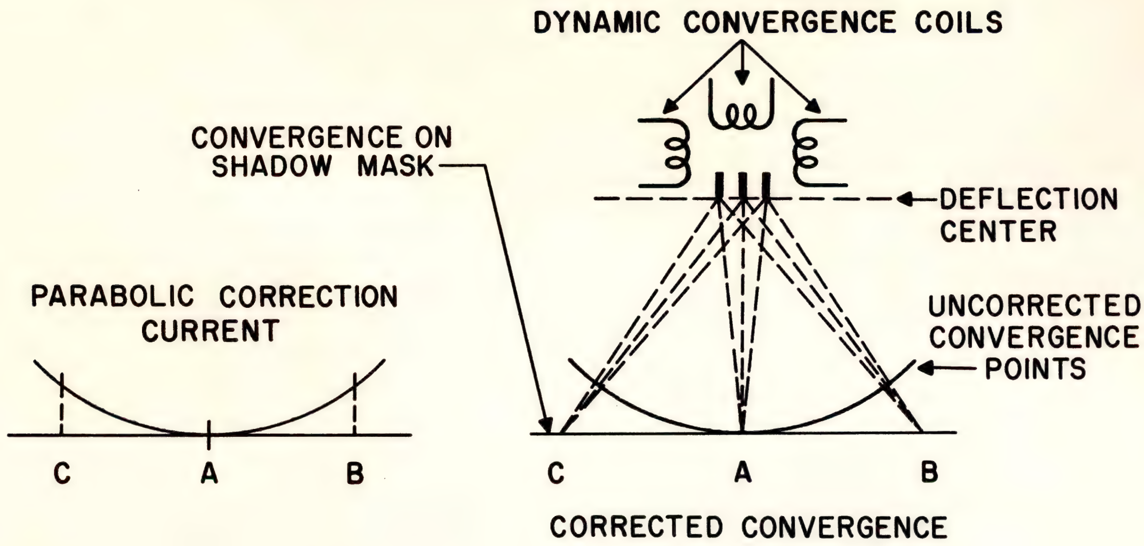


Figure 5-5. Corrective Waveform & its Effect on Focal Length

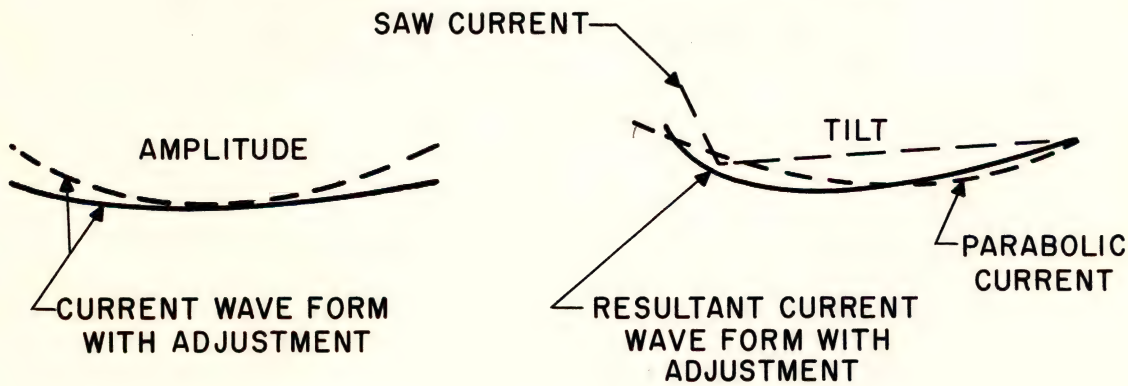


Figure 5-6. Amplitude & Tilt Action

tance from the yoke deflection center to the outer edges of the screen is greater than it is to the center. When the deflection system moves the three beams to the edge of the screen, the beams will converge at a point before reaching the mask. When the three beams reach the mask, they will have crossed and will light the screen in three different places. Figure 5-4 shows that the misconvergence caused by the tube is greatest at the edges of the screen. This can be corrected by making the focal length of the three beams variable in step with the vertical and horizontal sweep systems.

Coils wound on the convergence magnet assemblies are placed over each electron gun. Passing a current through the coils will cause the focal length, or the point where the beams cross over, to change. The amount of current required for convergence will be greatest when the sweep is at the edges of the screen and will gradually reduce until it becomes zero at the center where correction is not needed. Two coils are used on each convergence magnet assembly. One is used to correct misconvergence in a vertical plane and the other in the horizontal plane.

Figure 5-5 shows the corrective current waveform and its effect on focal length.

A 60 CPS and 15,750 CPS current of the waveform shown in Figure 5-5 is provided to maintain convergence as the tube is scanned vertically and horizontally. The 60 CPS parabola corrects vertical convergence errors and the 15,750 CPS parabola corrects horizontal convergence error. The amount and the waveshape of the current required for convergence will vary slightly from set to set, because of slight differences in the picture tube and other variables. Two controls are provided for each parabolic correction current, so that they can be adjusted for the particular picture tube and yoke combination. One control called an "amplitude control" adjusts the amplitude or the amount of current. The other control called a "Tilt Control" tilts the waveform of the current to insure that all points are converged. For convenience red and green convergence coils are usually connected in series. This

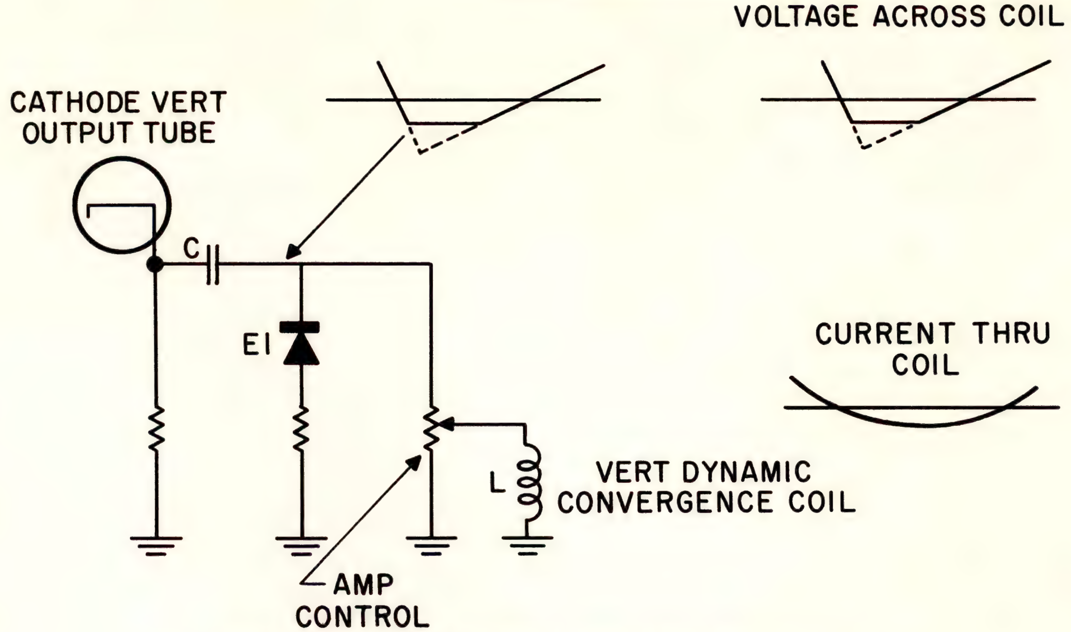


Figure 5-7. Circuit for Producing Vertical Parobolic Current

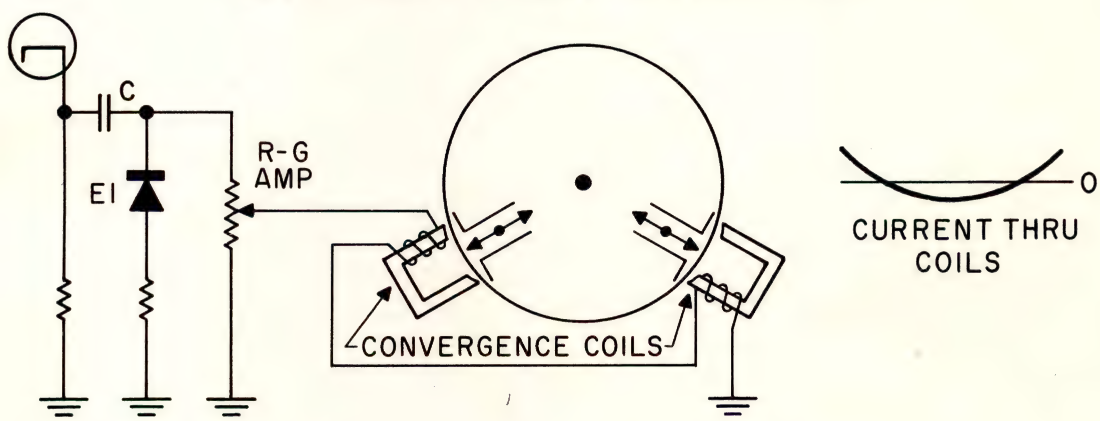


Figure 5-8. R-G Vertical Dynamic Amplitude Circuit

necessitates the addition of balance controls called "Differential tilt" and "Amplitude controls."

Figure 5-6 (left side) shows the action of an amplitude control. This control adjusts the magnitude or the amount of correction current through each convergence coil. The action of a tilt control is shown at the right side of Figure 5-6. The tilt circuit adds a saw current to the parabolic current and alters the current wave shape as shown. The tilt control adjusts the amount and the polarity of the saw current and becomes a waveform adjustment.

Vertical Dynamic Convergence Circuits

Obtaining a parabolic current at vertical scan frequency

The voltage for vertical dynamic convergence is obtained from a sawtooth voltage which is present on the cathode of the vertical output tube. Figure 5-7 shows the basic circuit for producing the parabolic convergence current.

The vertical sweep sawtooth current that passes through the vertical output tube will cause a sawtooth voltage to appear across the unbypassed cathode resistor. This sawtooth voltage passes through coupling capacitor C and is applied across the convergence coil. If the convergence coils were a pure inductance, this sawtooth voltage would produce the required parabolic current. The convergence coils, however, are resistive as well as inductive, so the saw voltage must be modified in order to produce a parabolic current through the coil. Diode E-1 limits the negative peak voltage as shown. This produces the correct voltage waveform to cause a parabolic current through the convergence coil. The amplitude control determines the voltage across the coil and, consequently, the amount of current.

The red and green electron guns occupy similar positions in the yoke deflection field, and their dynamic convergence circuits may be combined and fed from a single voltage source. Figure 5-8

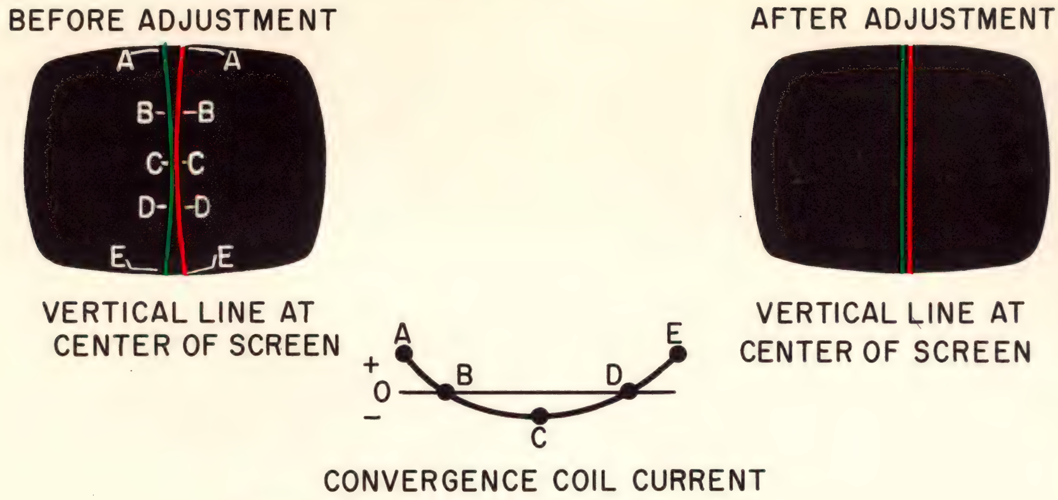


Figure 5-9. Effect of Vertical R-G Amplitude Adjustment

shows the vertical red-green dynamic convergence circuit and the beam movement.

With the red and green dynamic convergence coils connected in series, adjustment of the amplitude control will cause an increase or decrease of current in both coils.

Figure 5-9 shows the effect that is viewed on the screen when a parabolic current flows through the dynamic convergence coils.

On the left side of Figure 5-9 is shown vertical R-G lines through the center of the screen before the dynamic correction is applied. The center of the line (Point C) has been converged using the static adjustments. Without any dynamic correction, the misconvergence is progressively worse toward the edges of the screen as indicated. If we pass a current of the waveform indicated through the convergence coils, the beams will move in the direction indicated by the arrows. Point A on the current curve has maximum current and causes maximum displacement of the beams at Point A on the scan line.

At Point B (current curve), the current is zero so there is no action at Point B on the scan line. At Point C, the current has reversed, causing the center of the screen to misconverge in the direction indicated by the arrows at the center of the scan line. Again at Point D, the current passes through zero, so there is no movement at Point D on the scan line. The current becomes maximum at Point E and causes beam movement as indicated by the arrows at Point E. It should be noted that the beam movement at each edge of the screen (toward convergence) is greater than the movement (away from convergence) at the center of the screen. The diode in the waveforming circuit limits the peak voltage and, consequently, the current at the center of the screen. This allows a maximum of convergence action at the edges of the screen and a minimum of deconvergence at the center.

Once the amplitude is correctly adjusted, red should either be converged on green along the vertical line or symmetrically displaced as indicated in Figure 5-9. If parallel lines are obtained, they may be easily converged with the static adjustments.

The red and green vertical dynamic coils are connected in series and return to ground through a control connected across a secondary winding on the vertical output transformer. The deflection current flowing in the transformer will produce a pulse of voltage across the secondary winding. The waveform across the winding is quite different to the saw voltage developed across the cathode resistor of the vertical output stage. The inductive discharge from the vertical deflection yoke causes a pulse of voltage to appear across the secondary winding during vertical retrace. The voltage pulse does not appear across the cathode resistor, since the tube is biased beyond cut-off during vertical retrace.

The waveform of the secondary voltage is shown in Figure 5-10. At opposite ends of the winding, equal voltages of opposite polarity will appear. By connecting a control across the winding, varying amounts of positive or negative pulse can be selected.

The pulse of voltage across the convergence coils will cause a saw of current to flow. When the saw current is added to the parabolic current, waveforms as shown in Figure 5-10, will be produced. The pulse of voltage occurs during vertical retrace, so that the greatest change in current waveform will be at the beginning of the vertical retrace or top of the screen.

After the red-green amplitude is adjusted, a condition as shown in Figure 5-11 may be encountered. A red-green vertical line through the center of the screen is converged from the center down, but is either under- or over-converged from the center up. It is apparent that the dynamic current

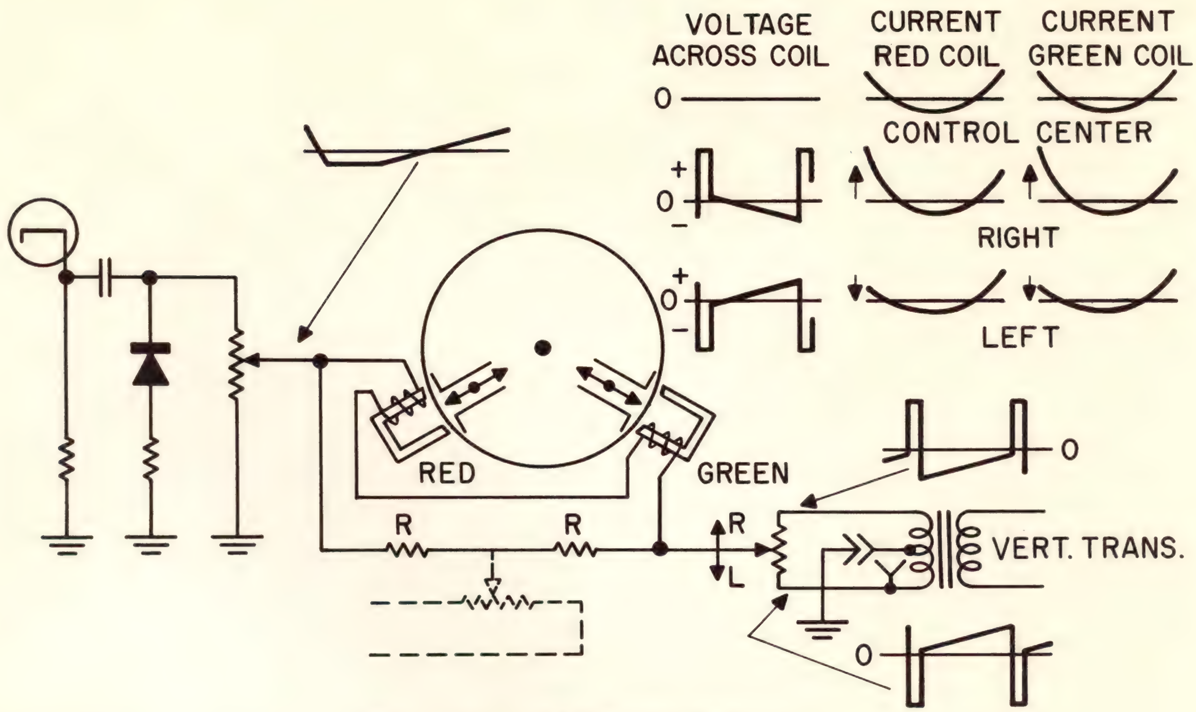


Figure 5-10. Vertical Dynamic Tilt Circuit

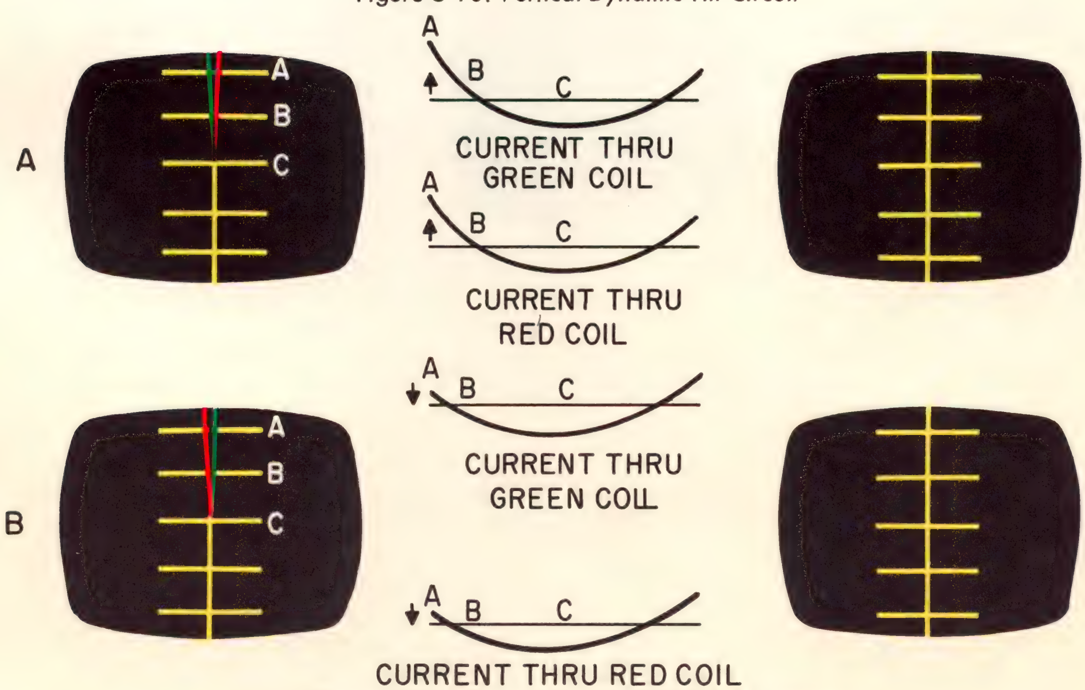


Figure 5-11. Effect of Vertical R-G Tilt Adjustment

waveform must be altered to produce the desired correction at the top of the screen without deconverging the bottom.

In Figure 5-11:A, red and green are under-converged from the center up. The tilt control is adjusted to add a positive pulse across the convergence coils. The positive pulse will increase the current through the convergence coils at the beginning of the vertical trace and will cause the red and green beams to move toward convergence as indicated by the arrows.

In Figure 5-11:B, red and green are over-converged. The tilt control is adjusted to produce a negative pulse across the coils which will reduce the current at the beginning of the vertical trace. The reduction in current will allow the beams to move toward convergence as indicated.

Since the red and green convergence coils are connected in series, a balance control is provided to insure that the current in each coil is equal. This

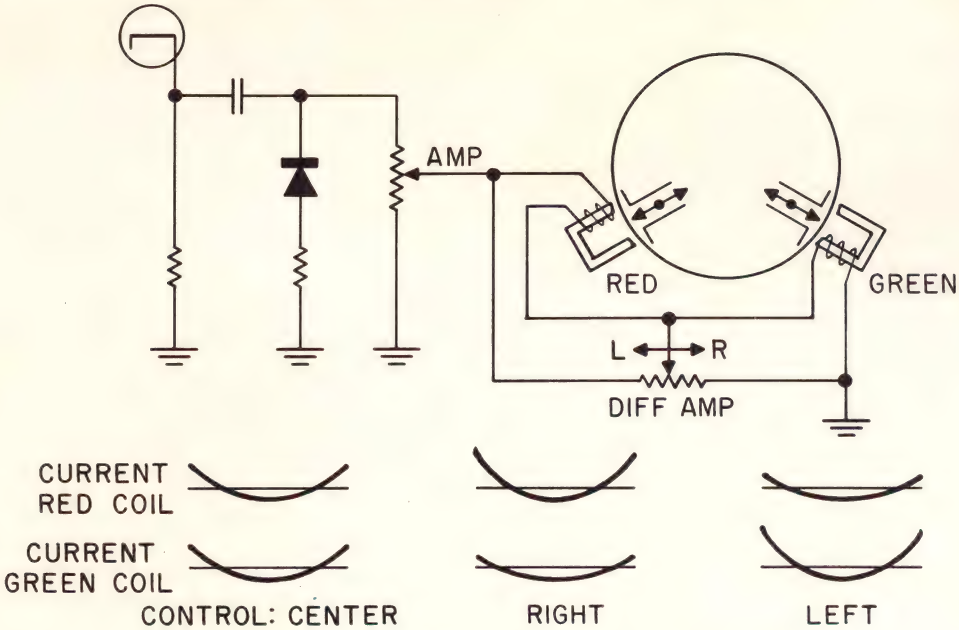


Figure 5-12. Vertical R-G Differential Amplitude Circuit

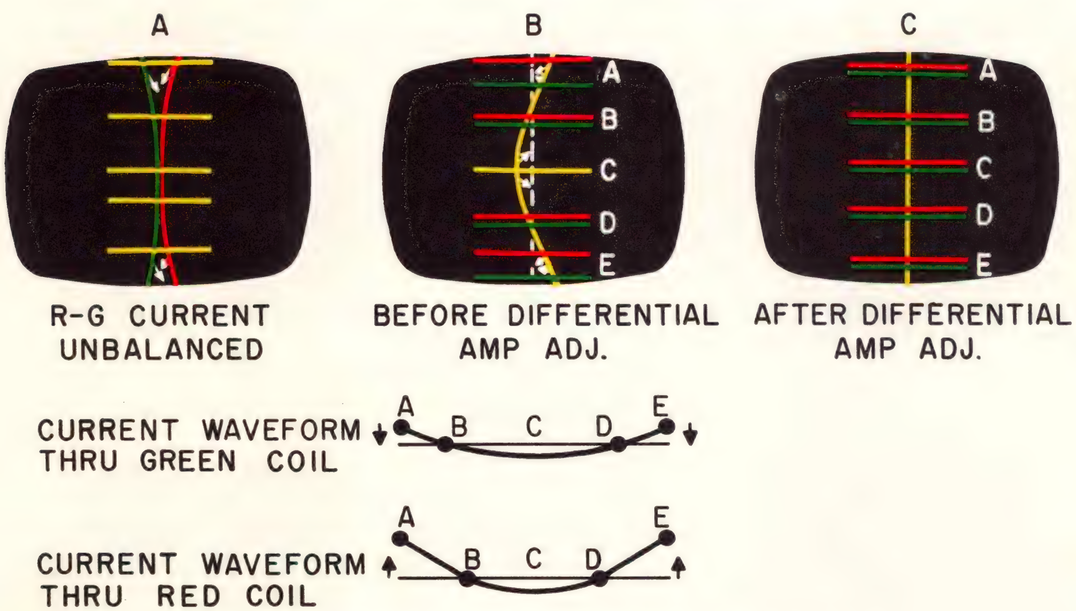


Figure 5-13. Effect of Vertical Differential Amplitude Adjustment

control will allow for production variations in the coils and the CRT. The circuit is shown in Figure 5-12. The balance or differential amplitude control is connected, so that a portion of the resistance is across each coil. As the control is adjusted, resistance is taken from across one coil and placed across the other. Since the resistance across the coils is adjustable, the distribution of current through the coils can be controlled.

As the current through the red and green convergence coils is increased with the amplitude control, a condition as in Figure 5-13:A may be encountered. In this case, the current in the two coils is not equal and green is moved further than red. With this condition, the beams are converged along a vertical line as in Figure 5-13:B. However, examination of horizontal lines near the top and bottom center of the screen will show that red and green are vertically displaced. Also, the vertical line has a slight bow in it. If the differential amplitude control is adjusted, so the current through the red coil is increased and the current through the green coil is decreased, the beam movement will be as indicated in Figure 5-13:B. This control is adjusted for convergence of red and green along horizontal lines near the bottom center of the screen. Adjustment is made for either convergence or symmetrical displacement as in Figure 5-13:C which can be con-

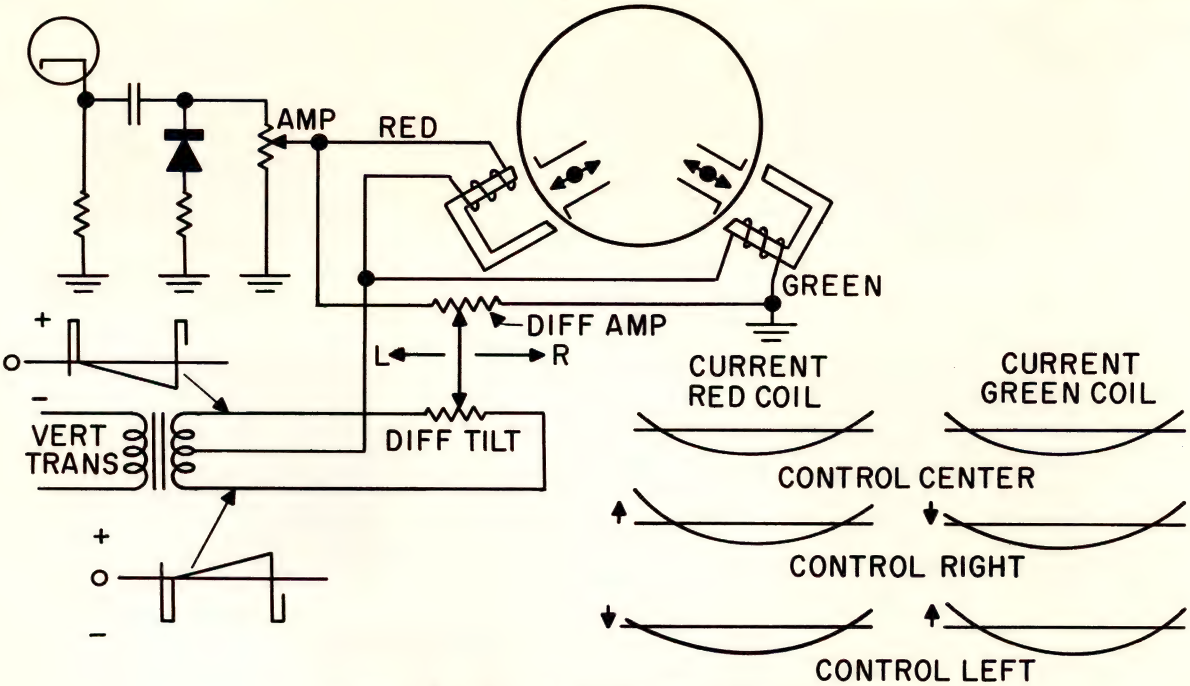


Figure 5-14. Vertical R-G Differential Tilt Circuit

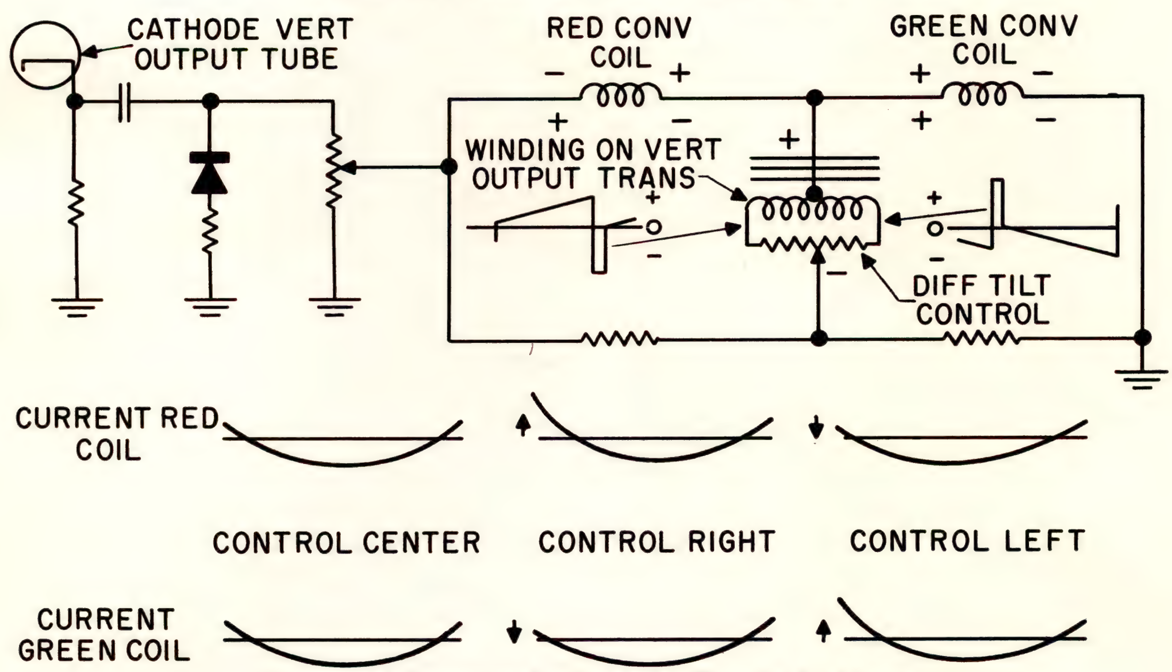


Figure 5-15. Equivalent Vertical R-G Differential Tilt Circuit

verged with the static adjustments.

The fourth, and final circuit needed to provide vertical red-green dynamic convergence is a differential tilt circuit. The basic circuit is shown in Figure 5-14.

The differential tilt control is a balance control for current waveform. The previously discussed tilt circuit adds a pulse of voltage across the red-green convergence coils and the differential tilt control adjusts the tilt voltage division between the coils.

To acomplish this balancing action, the differential tilt circuit provides opposite tilt action to current waveforms through the red-green dynamic convergence coils. A center tapped secondary winding on the vertical output transformer supplies varying amounts of either a positive or negative pulse voltage, depending on the setting of the differential tilt control.

Figure 5-15 shows an equivalent red-green differential tilt circuit. A center tapped secondary winding on the vertical output transformer is connected as shown. A positive pulse will appear from the center tap to one end of the secondary winding and a negative pulse from the tap to the other end

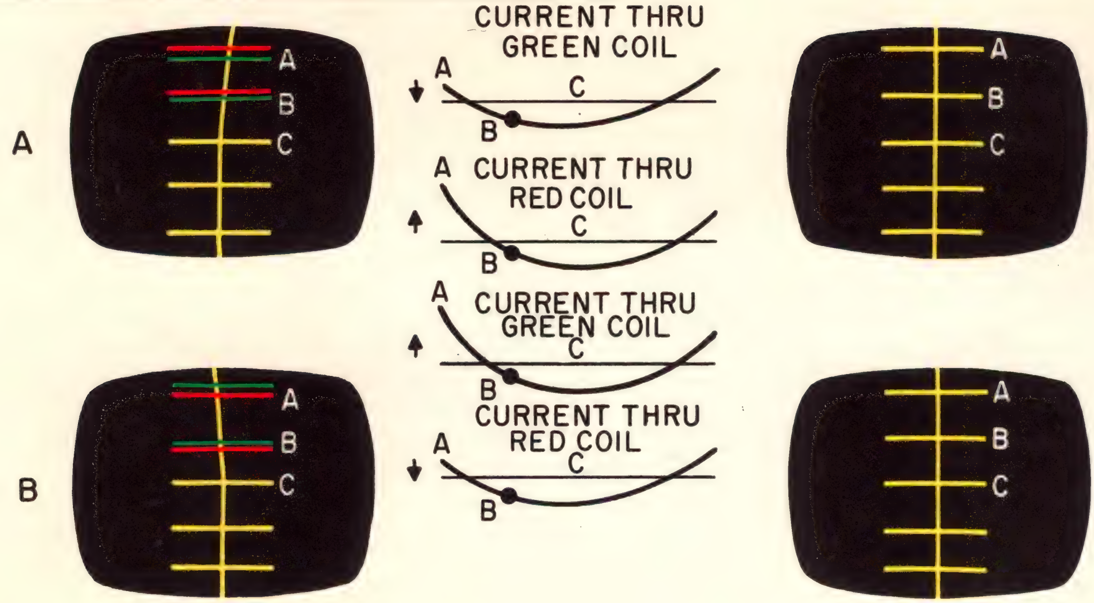


Figure 5-16. Effect of R-G Vertical Differential Control

of the winding.

If the differential control is adjusted to the left as shown, a negative going pulse will appear at the arm of the control, again using the center tap as a reference. This pulse will cause a voltage to develop across the two convergence coils as indicated by the polarity signs above the two coils. The saw voltage from the cathode of the vertical output tube, also causes a voltage to develop across the coils as indicated by the polarity signs below the coils. When these voltages are combined, the current through the red coil will be reduced and the current through the green coil will be increased. Since the voltage supplied by the winding on the output transformer is of a pulsed nature and occurs during vertical retrace, the major current changes will be at the beginning of the vertical trace or at the top of the screen. With the control to the left, the current waveform will be as indicated in Figure 5-15. When the control is moved to the right, opposite action occurs and the tilt is in the opposite direction.

To make the vertical differential adjustment, a horizontal line near the top center of the screen is observed. Figure 5-16:A shows red and green converged along a vertical line through the center of the screen; however, red and green are displaced along a horizontal line in the top center of the screen. Red is under-converged and green is over-converged. The differential tilt control is adjusted to increase red coil current, and reduce green coil current at the beginning of the trace. The two beams will move toward convergence as indicated by the arrows.

Figure 5-16:B shows the opposite condition. The control is adjusted in the opposite direction and beam travel is in the direction shown.

The four controls needed for vertical red-green dynamic convergence are amplitude, tilt, differential amplitude and differential tilt. The amplitude control adjusts the amount of current through the coils. The tilt control adjusts the waveform of the current. The differential controls are balance controls made necessary because the two coils are connected in series. They balance the current and waveform between the two coils.

The blue electron beam also requires a vertical dynamic current in order to converge it on red-green, which are now in convergence. The blue electron beam occupies a position in the yoke field which is unlike either of the other two beams, so it must be controlled by separate circuits. Since there is only one convergence coil, balance or differential controls are unnecessary. Only an amplitude and a tilt control are needed. The basic circuit is shown in Figure 5-17.

The voltage developed at the cathode of the vertical output tube is also used to supply the blue vertical dynamic circuit. A control is connected in series with the red-green amplitude control. A saw of voltage of variable amplitude is available at the arm of the control. The diode modifies this voltage so that it will produce a parabolic current through the blue convergence coil. The coil returns to ground through a center tapped secondary winding on the vertical output transformer. This winding supplies a positive or negative pulse as selected by the tilt control and applies it across the blue convergence coil. This voltage adds to the saw voltage across the coil and provides a current waveform adjustment in the same manner as the red-green tilt adjustment.

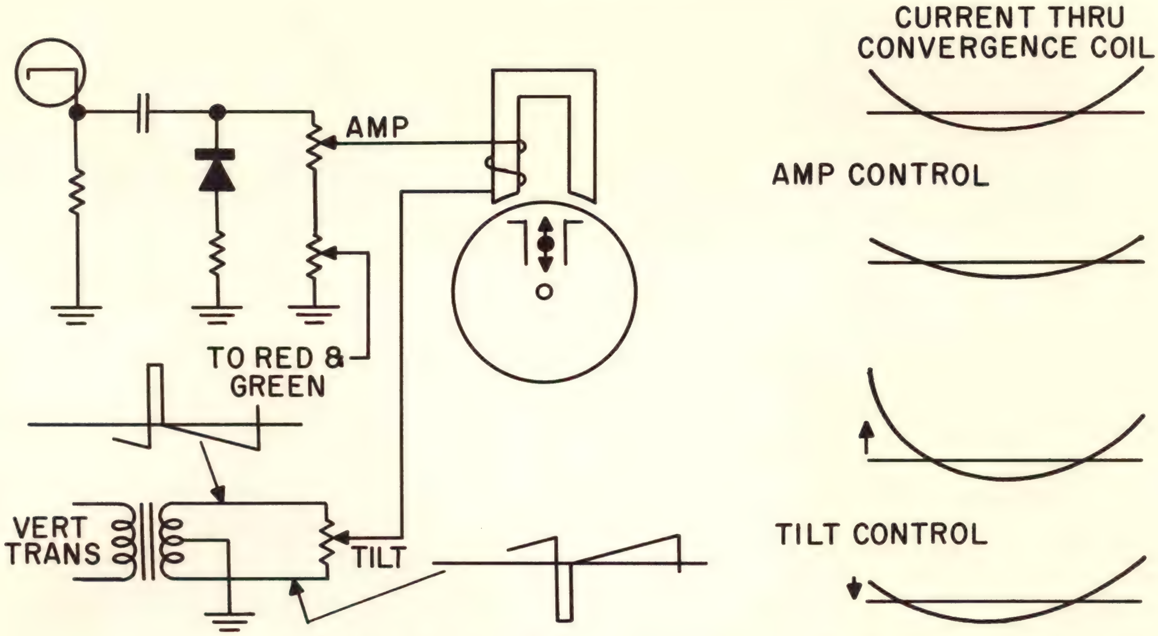


Figure 5-17. Blue Vertical Dynamic Convergence Circuit

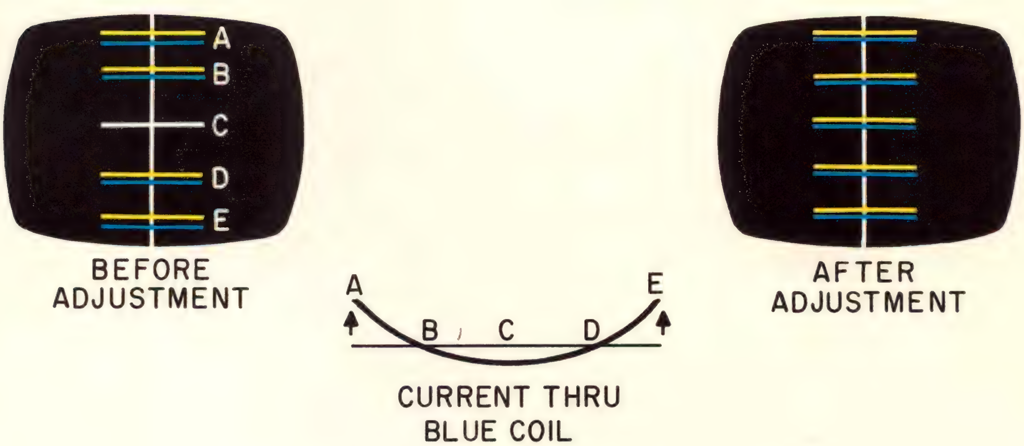


Figure 5-18. Effect of Vertical Blue Amplitude Control

Figure 5-18 shows the effect of increasing the blue dynamic amplitude.

The blue dynamic amplitude adjustment is made by observing horizontal lines near the top and bottom center of the screen. Figure 5-18 shows the normal misconvergence of blue before any dynamic correction is made. Blue is converged on red-green at the center of the screen using the static adjustments. Before dynamics are added, blue will be displaced from red-green at the top and bottom center as shown. As the amplitude control is advanced, the saw voltage will cause a parabolic current to flow through the blue convergence coil as shown. Blue will be displaced upward at the top and bottom of the screen and will be displaced downward at the center of the screen. The amplitude control should be adjusted for either convergence of blue on red-green along horizontal lines through the center of the screen, or for symmetrical displacement as shown in Figure 5-18. Once blue is symmetrically displaced from red-green, it can be converged using the static adjustments.

If, after blue amplitude is adjusted, it is not possible to converge blue on red-green, it may be necessary to change the waveform of the blue convergence current by adjusting the tilt control. Figure 5-19 demonstrates the need for tilt adjustment. Blue is converged from the center down, but is displaced in the top center of the screen. The tilt control is adjusted so that current through the convergence coil is increased at the beginning of the trace. Blue will be displaced upward in the top center of the screen

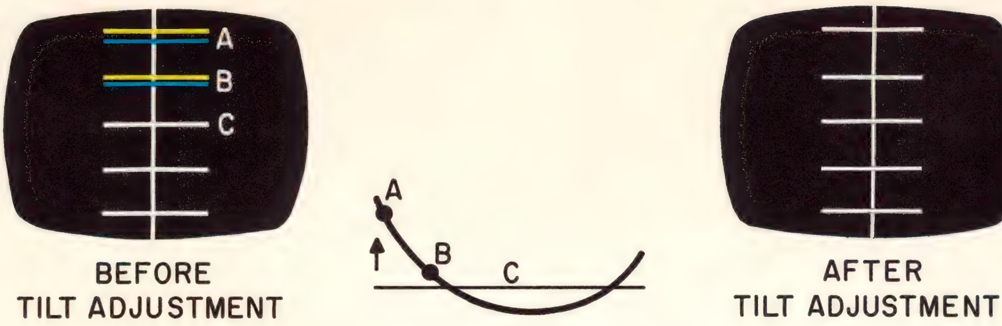


Figure 5-19. Effect of Vertical Blue Tilt Adjustment

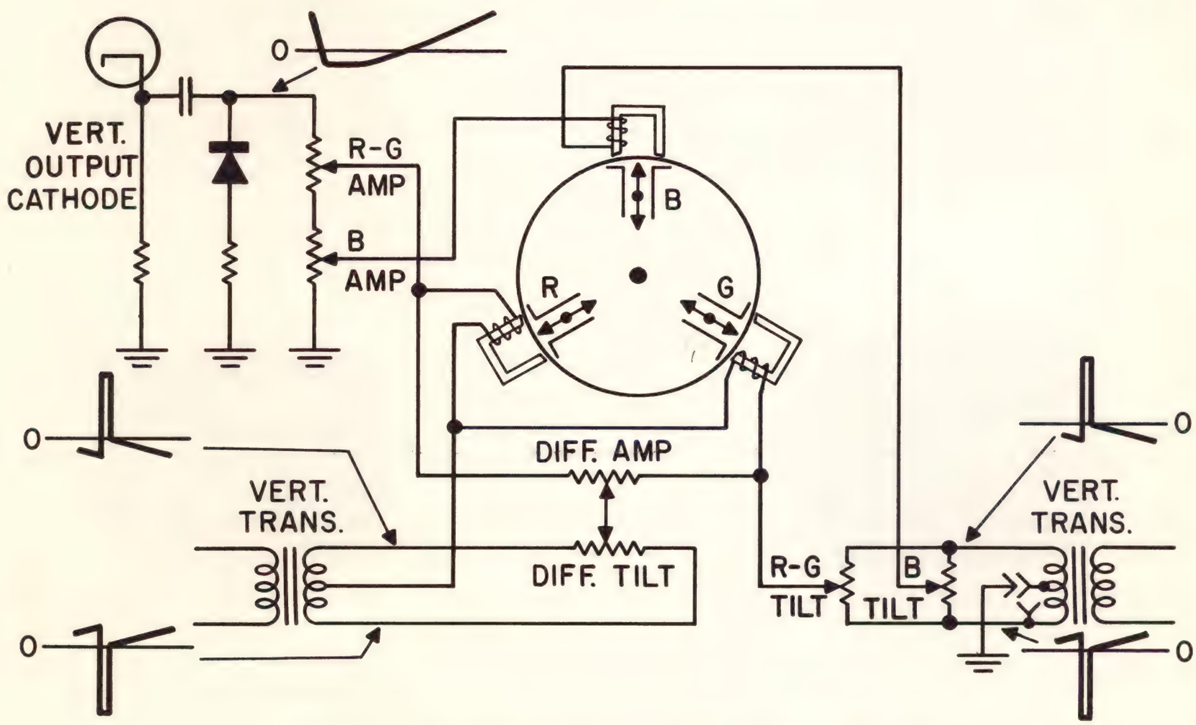


Figure 5-20. Complete Vertical Dynamic Convergence Circuit

where the misconvergence was present.

The complete vertical dynamic convergence circuit is shown in Figure 5-20.

Horizontal Dynamic Convergence Circuits

The previously discussed convergence circuitry serves to maintain convergence as the screen is scanned vertically. A dynamic correction (synchronized with the horizontal sweep system) is necessary to maintain convergence with horizontal sweep. To accomplish this, circuitry is provided to produce a parabolic current that is locked in time with the horizontal scan system. Controls are provided to adjust the amount (or amplitude) of current and the waveform. The action of the horizontal dynamic convergence controls is quite similar to the equivalent vertical control. The area of the screen to be viewed during adjustment, however, is different.

The circuitry to produce a parabolic current at the horizontal scan frequency is different from that used to produce a parabolic current at the vertical frequency for two reasons. The higher horizontal scan frequency (approximately 15 KC) makes it practical to use resonant circuits for increased efficiency. The increased efficiency will reduce the amount of power taken from the horizontal sweep system. The second difference is the waveform of the voltage available in the horizontal deflection system. The vertical system contained a saw voltage which is near the required waveform. The voltage available in the horizontal system is a pulse of short duration caused by the inductive discharge of the deflection yoke. Circuitry is provided to change the pulse to the proper waveform to cause a parabolic current in the convergence coils.

Figure 5-21 shows the basic circuit for blue horizontal dynamic convergence.

Inductance L-1 and the impedance of the conver-

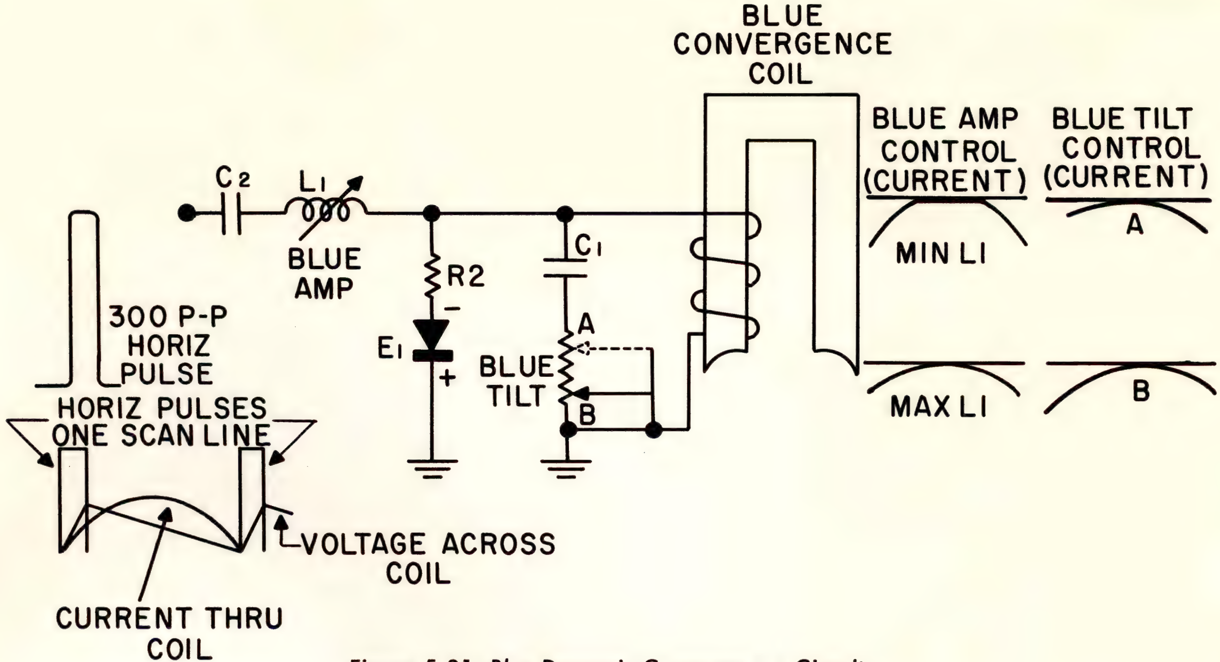


Figure 5-21. Blue Dynamic Convergence Circuit

gence coil forms the pulse from the horizontal output transformer into a saw voltage. This saw voltage appears across the convergence coil. The inductance of L-1 is made adjustable, so the voltage across the convergence coil can be varied. The current through the coil will vary with the voltage and provide current amplitude control.

The convergence coil is made parallel resonate by capacitor C-1. This will increase the efficiency of the convergence circuit and reduce the amount of power taken from the horizontal scan system. The coil must be resonate at a frequency somewhat lower than the scan frequency. It is resonated so that it completes ½ cycle in the time it takes the beam to scan from the left to the right side of the picture tube.

Figure 5-21 shows the pulses from the horizontal transformer, the developed saw voltage and the resulting current.

A control RI is provided to adjust the shape of the waveform of the current through the convergence coil. This is accomplished by connecting a variable resistor in the tuned circuit formed by C-1 and the convergence coil. As the control is adjusted to position A, Figure 5-21, resistance is removed from the circuit and when adjusted to Position B will add maximum resistance to the circuit. As resistance is added, the current waveform through the coil will become more like the waveform of the applied voltage which is saw shaped. As it becomes more saw shaped, the current at the beginning of trace (left side of screen) becomes greater than at the end of trace. With the control in the other direction, the current waveform becomes less saw like and the current amplitude at the beginning of trace is less than at the end of trace. The current waveforms that result are shown in Figure 5-21. Since this control changes the current waveform at the beginning of trace, its effect on convergence is viewed at the left side of the screen.

Each of the horizontal dynamic circuits employ a system of DC clamping to maintain center convergence, as the edges of the screen are brought into convergence. This adds to the ease of adjustment and does away with the need for making static adjustments as the horizontal dynamics are adjusted.

Figure 5-22 shows an equivalent DC clamping circuit.

As established earlier, the pulse from the horizontal transformer is integrated into a saw shaped voltage by L and R, see Figure 5-22. Without diode E, the AC axis (the electrical center of the developed saw voltage) would be zero after passing through capacitor C. That is, a portion of the saw would be positive and the other portion negative.

With the diode connected, the positive portion of the saw voltage will cause the diode to conduct and produce a negative DC voltage at Point A, or across the resistance of the convergence coil.

The negative voltage developed by the diode will displace the AC axis downward as shown so that the peak of the saw voltage is zero and all other portions are negative. If the amplitude control is adjusted to increase the amplitude of the saw voltage, a greater negative voltage will develop at Point A, moving the AC axis still further negative. In this manner, the peak saw voltage is clamped at the zero line. The parabolic current that flows as a result

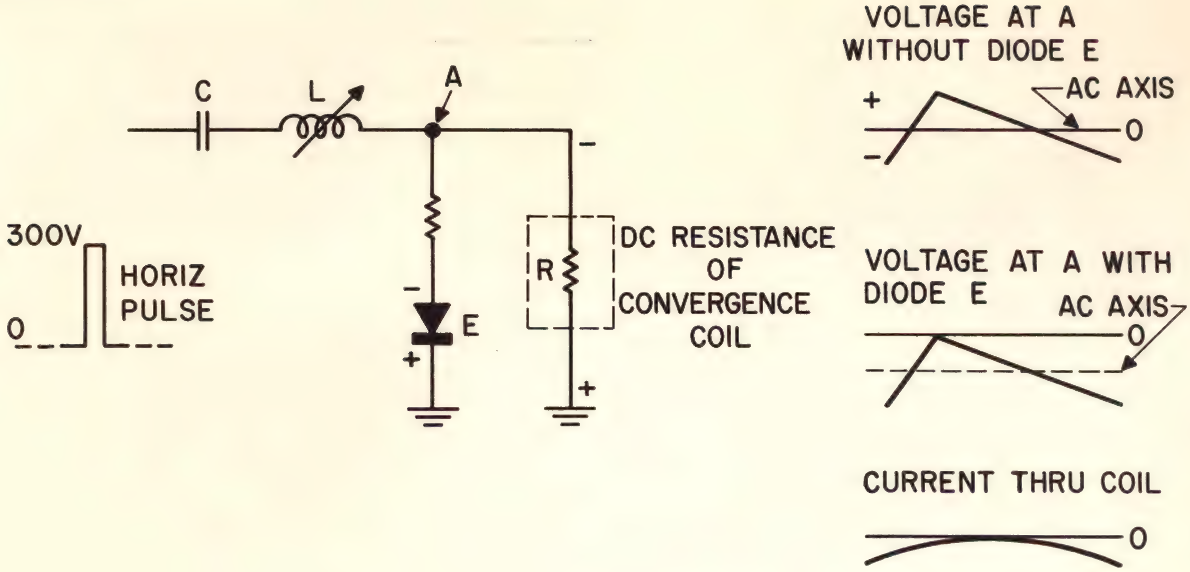


Figure 5-22. DC Clamping of Horizontal Convergence Circuit

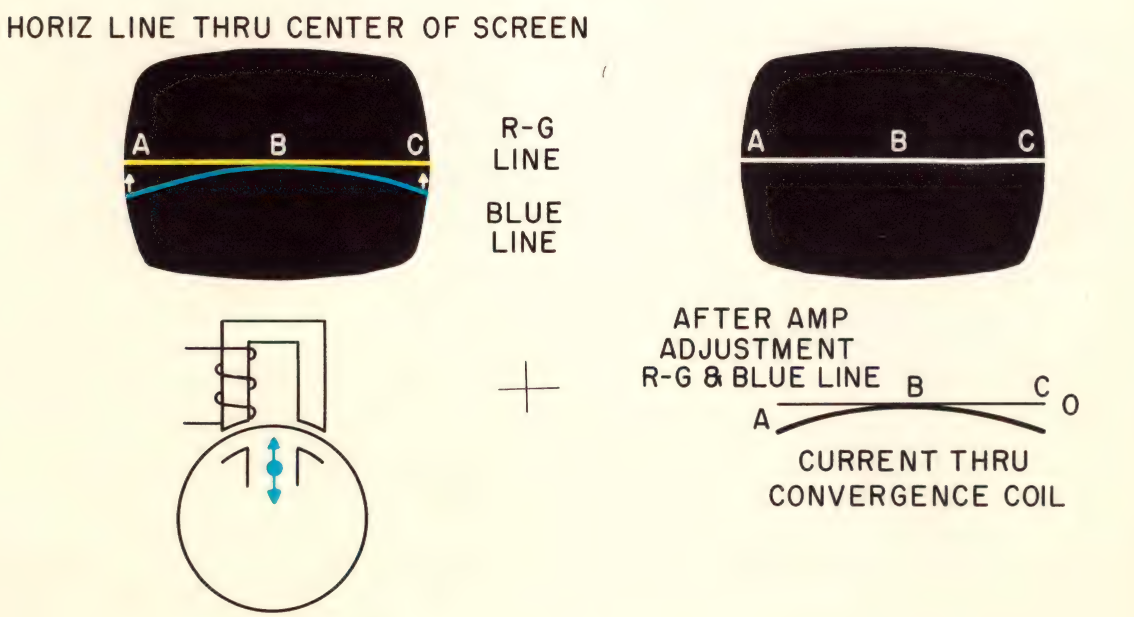


Figure 5-23. Effect of Blue Horizontal Amplitude Adjustment

of the negative saw voltage will also have its peak clamped at the zero line as shown. The peak of the parabola occurs at the center of the sweep or the center of the screen. Because of the clamping action, the convergence current is always zero at this point so convergence at the center of the screen is not affected by horizontal dynamic adjustments.

Figure 5-23 shows blue deconverged from red-green on a horizontal line through the center of the screen, as it normally is after static center convergence, but before dynamic convergence corrections are added. As the blue horizontal amplitude is adjusted to increase the current through the convergence coil, blue is deflected upward as shown by the arrows. Maximum change occurs at Points A and B since current through the coil is greatest at these two points. The DC clamping makes the current through the coil zero at Point B so center convergence is not affected. The amplitude control is adjusted so that blue is converged at all points between B and C on the horizontal line.

After blue is converged with red-green on the right side of the screen, with the blue amplitude adjustment, the left side may not be converged. Two conditions are shown in Figure 5-24. Blue is under converged in the top example and over converged

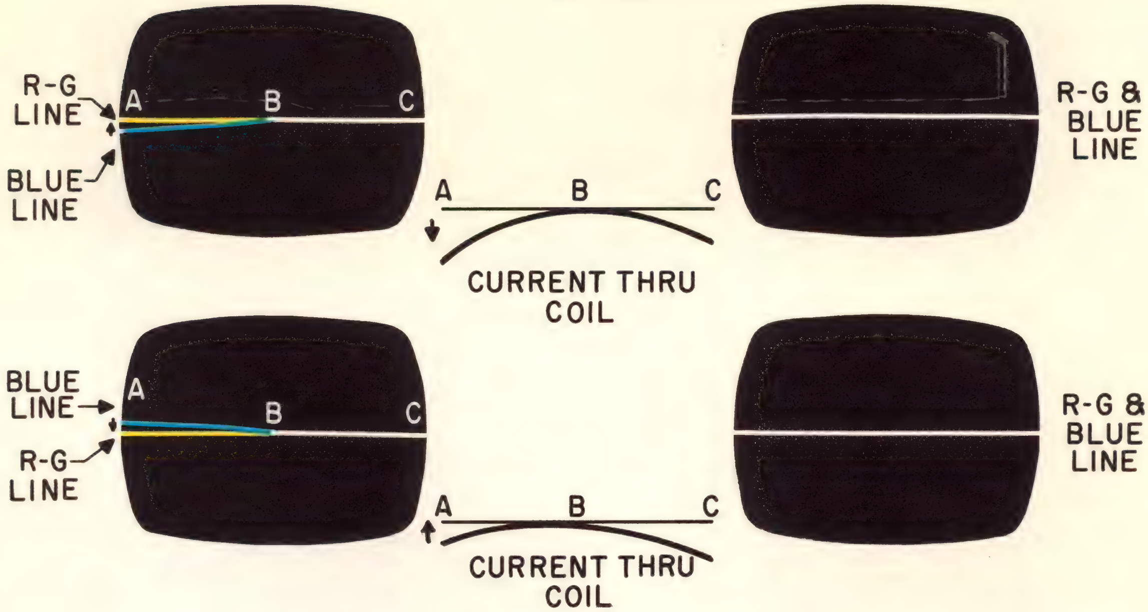


Figure 5-24. Effect of Blue Horizontal Tilt Adjustment

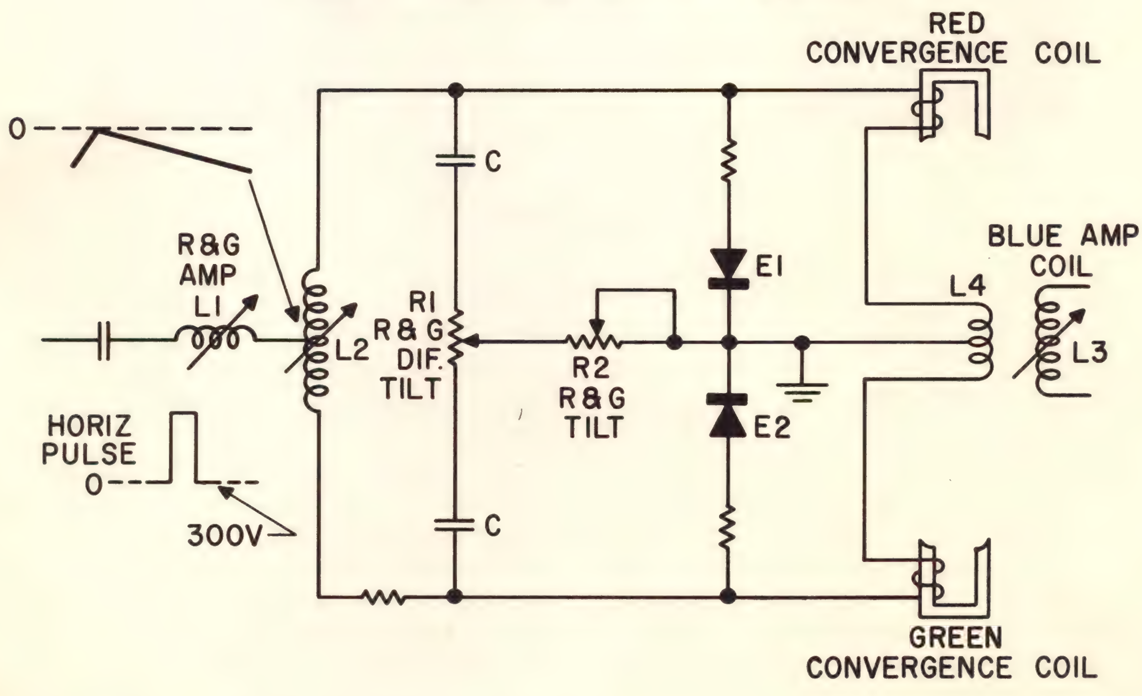


Figure 5-25. Red & Green Horizontal Dynamic Convergence Circuit with Clamping

in the other. The blue horizontal tilt control will either increase or decrease the current through the convergence coil at the beginning of the trace, so will correct misconvergence on the left side of the screen. The left side of a horizontal line through the center of the screen is observed and the tilt control is adjusted for convergence of blue on red-green.

The circuitry required for red-green dynamic convergence is quite similar to the previously discussed blue horizontal convergence circuit. Since the red and green electron beams occupy the same relative position in the yoke field, they require the same type of convergence correction and may be fed from a common voltage source. Figure 5-25 shows the dynamic red-green convergence circuit.

The red-green horizontal dynamic convergence circuitry consists of two circuits of the type used for blue, connected in parallel and fed from a single voltage source. Each convergence coil is made parallel resonate at 12.5 Kc by capacitor C. Operation of the amplitude and tilt circuitry is exactly the same as previously discussed in the blue horizontal dynamic circuit. Inductance L-1 is adjustable and controls the amount of voltage across the two conver-

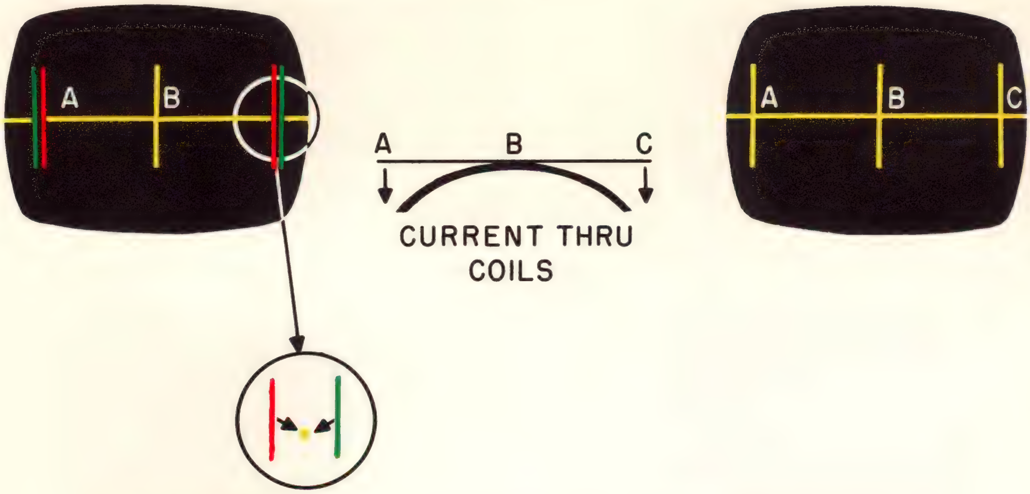


Figure 5-26. Effect of Horizontal Red-Green Amplitude Adjustment

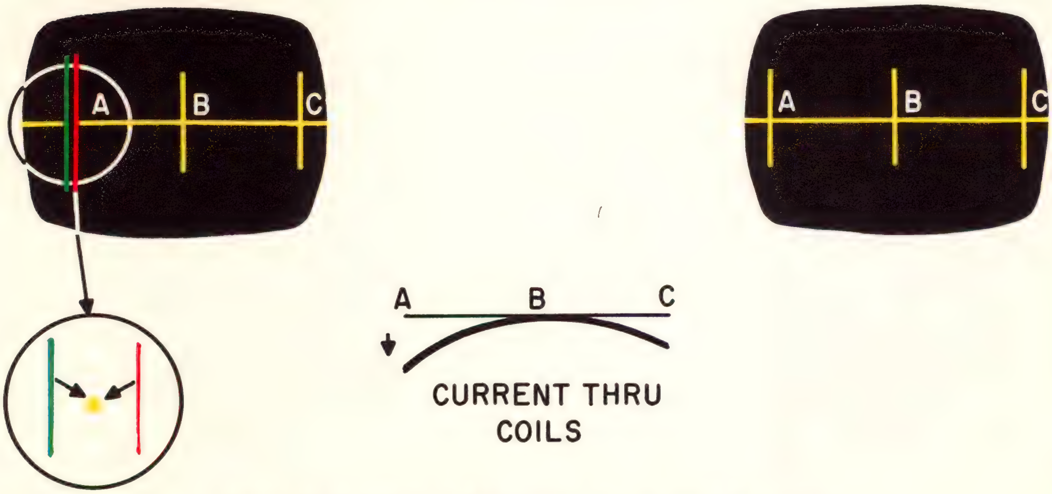


Figure 5-27. Effect of Red-Green Horizontal Tilt Control

gence coils and consequently, the amplitude of current. Control, R-2, adds or removes resistance from the two tuned circuits simultaneously to provide the necessary tilt action. As was the case with red-green vertical convergence circuits, we have two circuits ganged together so controls are provided to balance the current and waveforms between the two coils. These two controls are called "Differential Amplitude" and "Differential Tilt."

The adjustable inductive voltage divider, L-2, determines how the voltage divides between the two convergence coils. By adjusting the voltage division, the balance of current between the coils can be varied.

The differential tilt control operates in the same manner as the tilt control except that as resistance is added to one tuned circuit, it is removed from the other and causes opposite tilt action to the two convergence current waveforms. Both the tilt and differential tilt controls vary the current waveform at the beginning of trace or at the left side of the screen.

A red-green horizontal line through the center of the screen is shown on the left in Figure 5-26. Red and green are converged along a horizontal line, but examination of vertical lines at either end of the horizontal line, will show that they are misconverged in that plane. This is the normal misconvergence of red and green before any dynamic corrections are applied. As the horizontal red-green amplitude control is adjusted to increase the current through both convergence coils, the electron beams will move in the direction indicated by the arrows. Figure 5-26 (center) shows the current through the red-green coils. The current is maximum at Points A and C where maximum correction is needed. The DC clamping causes the current to be zero at Point B so convergence at the center of the screen is not affected. The amplitude control is adjusted for convergence of red on green while viewing vertical lines on the right side of the screen.

After the red-green amplitude is adjusted for convergence of vertical lines on the right side, there is

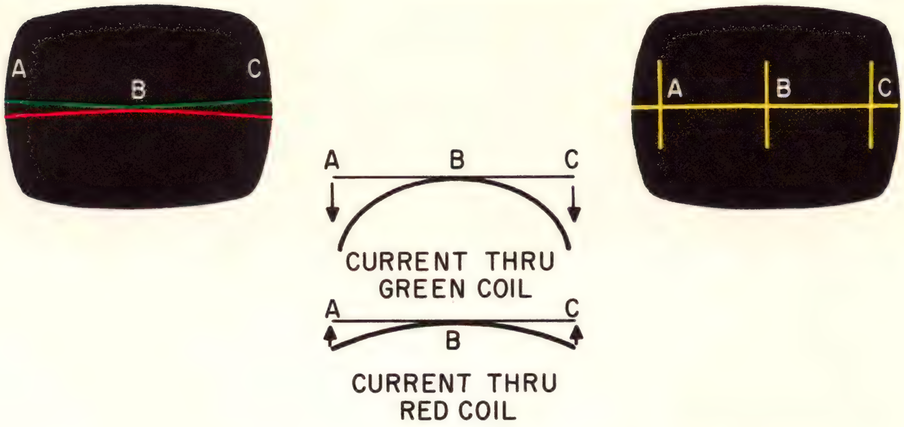


Figure 5-28. Effect of R-G Horizontal Differential Amplitude Control

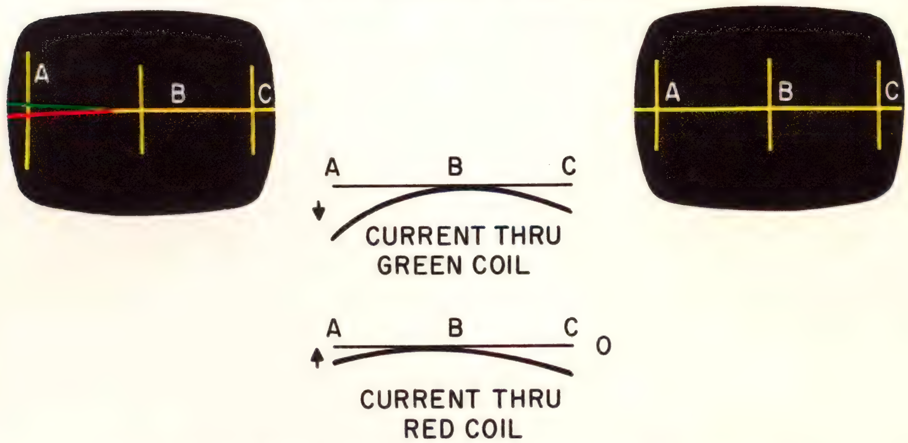


Figure 5-29. Effect of R-G Horizontal Differential Tilt Adjustment

a possibility that vertical lines on the left side of the screen may not be converged. An example is shown in Figure 5-27. To correct this condition, an increase in current through the convergence coils is required at the beginning of the horizontal trace. The tilt control provides this action. As the control is rotated toward maximum resistance, the current at Point A (current curve, Figure 5-27) will increase while there will be little or no change of current at Point C. This will allow convergence on the left side without de-converging the right side of the screen. The DC clamping circuit will maintain center convergence.

After red is converged on green by viewing vertical lines on either side of the screen and adjusting horizontal amplitude and tilt, they may not be converged along a horizontal line. An example is shown in Figure 5-28. The deconvergence along the horizontal line is a result of the current not being balanced between the red and green convergence coils. The differential amplitude control is used to adjust or balance the two currents.

In the above example, the green coil needs additional current and the red coil needs less current in order to bring red-green into convergence. The differential amplitude control is adjusted for convergence by viewing horizontal lines on the right side of the screen. The convergence action is as indicated by the arrows.

After the differential amplitude control is adjusted for convergence of red-green on horizontal lines on the right side of the screen, there may be some convergence error on the left side. An example is shown in Figure 5-29. This condition is caused by a waveform unbalanced between the two coils. The differential adjustment will redistribute the tilt voltage between the coils and increase the tilt action in one, and decrease it in the other.

Correction of the misconvergence, in the example shown, will require an increase of current in the green coil and a decrease in the red coil at the beginning of the trace. This adjustment is made while viewing red-green horizontal lines on the left side of the screen. Beam movement is in the direction indicated by the arrows.

From the preceding discussion of the dynamic convergence circuits, it should be apparent that the amplitude controls will affect convergence in two areas of the screen while the tilt controls will affect only one area. If the dynamic adjustments are made in the proper order, the set may be converged by viewing only one area of the screen at a time.

6 / Adjustment of the Convergence Circuits

The static and dynamic convergence adjustments are made while viewing the screen. A generator is connected to the set to produce a cross-hatch pattern on the screen. This pattern will turn the three electron beams "on" and "off" several times with each vertical and horizontal scan. By viewing the lines in the pattern, we can determine if the three rasters (red, green and blue) are superimposed or converged in all areas of the screen. If the rasters are converged, the three beams will turn "on" at the same point and the lines in the pattern will appear white. If the three rasters are not converged, the three beams will be turned "on" at slightly different points and the individual rasters will be seen as colored lines and indicate a need for adjustment.

The static magnets are adjusted first for convergence while viewing a small area in the center of the screen. The dynamic convergence controls are then adjusted to converge the outer areas of the screen. Most of the misconvergence in these areas is caused by the projection of the three rasters on the flat screen and can be resolved into misconvergence caused by either the vertical or the horizontal travel of the beams.

Figure 6-1:A shows a vertical line through the center of the screen. Along this line, the horizontal sweep is zero, so any misconvergence observed must be caused by the vertical travel of the beams and, therefore, correctable with the vertical dynamic controls.

Figure 6-1:B shows a horizontal line through the center of the screen. Along this line, the vertical sweep is zero, so any misconvergence observed must be caused by the horizontal travel of the beams and, therefore, correctable with the horizontal dynamic controls. If all points along these two lines are converged, all other areas of the screen should also be converged, since they receive a combination of vertical plus horizontal correction. A small vertical area through the center of the screen is observed to adjust the vertical dynamic adjustments and a small horizontal area through the center of the screen is observed to adjust the horizontal dynamic adjustments.

The horizontal and vertical dynamic circuits each, usually, have four controls. They are:

Amplitude
Tilt
Differential Amplitude (balance)
Differential Tilt (balance)

The vertical and horizontal controls are similar in function and differ principally in the area of the screen viewed during adjustment.

All of the "amplitude" and "differential amplitude" controls will affect convergence in two areas of the screen while the "tilt" and "differential tilt" controls, to a large degree, affect only one area. For example, if the "vertical amplitude" control were adjusted, action would be observed at the top and bottom of a vertical line through the center of the screen while the "vertical tilt" control would affect only the top of the line. An order of adjustment can then be established for ease of dynamic convergence. The "vertical amplitude" control is first adjusted for convergence by viewing the vertical line

Figure 6-1. Resolving Horizontal & Vertical Convergence Errors into Horizontal & Vertical Lines

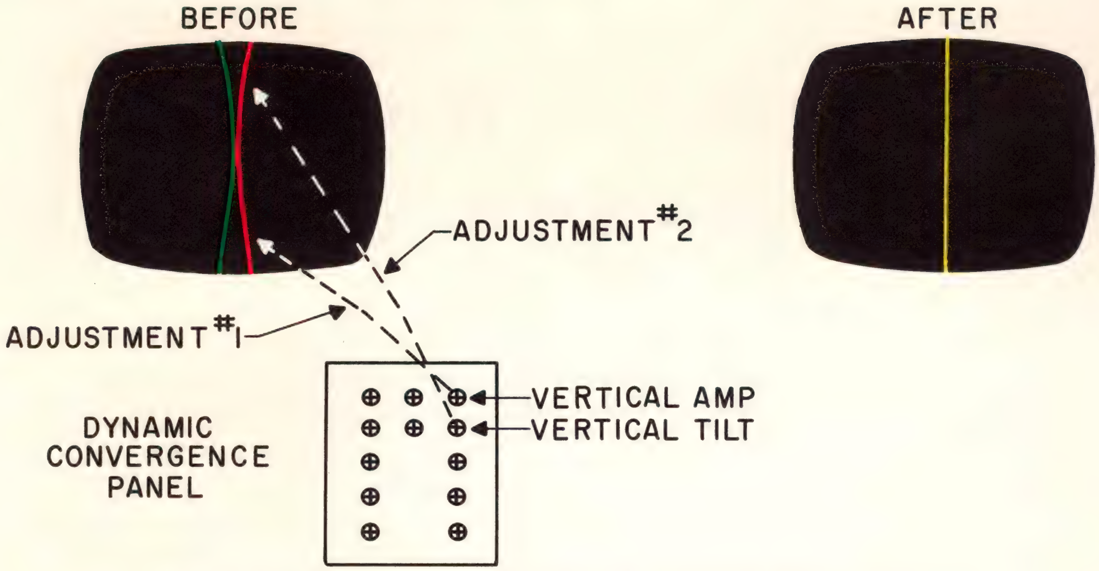


Figure 6-2. Adjustment of Vertical Dynamic Amplitude & Tilt Controls

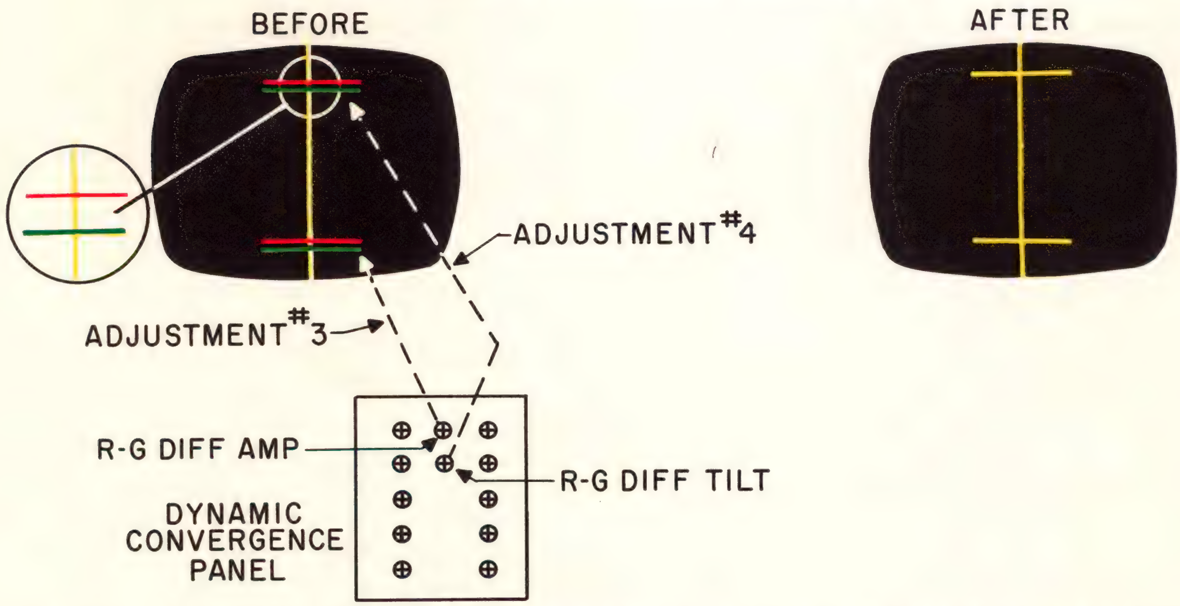


Figure 6-3. Adjustment of Vertical Dynamic R-G Differential Amplitude & R-G Differential Tilt Controls

at the bottom of the screen and then the vertical tilt control is adjusted to correct any remaining misconvergence along the top of the vertical line. See Figure 6-2.

The first two adjustments to be made, as the set is brought into convergence, are the vertical red-green "amplitude" and "tilt" adjustments. The blue raster is not used and the blue gun may be turned off if desired by rotating the blue screen control counterclockwise.

The vertical red-green amplitude control is adjusted for convergence of red on green by observing a vertical line from the center to the bottom of the screen. The vertical red-green tilt control is then adjusted so that red is converged on green on the same vertical line from the center to the top of the screen. See Figure 6-2.

The third and fourth adjustments are the "differential amplitude" and "differential tilt." The "differential amplitude" control is adjusted for convergence of red on green by viewing a short section of a horizontal line near the bottom of the screen at the point it crosses the vertical line as shown in Figure 6-3. The "differential tilt" is adjusted to converge red on green by viewing a horizontal line near the top of the screen at the point it crosses the center vertical line.

The misconvergence, corrected by these two controls, is caused by the vertical travel of the beams but it is necessary to observe horizontal lines near the top and bottom center of the screen in order to see the error. This is the case when red and green

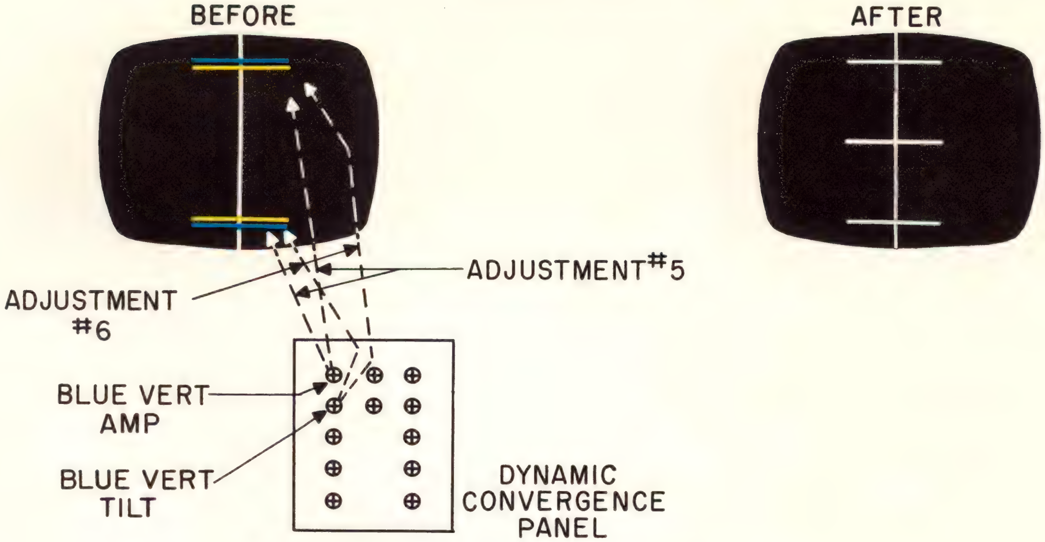


Figure 6-4. Adjustment of Blue Vertical Dynamic Amplitude & Tilt Controls

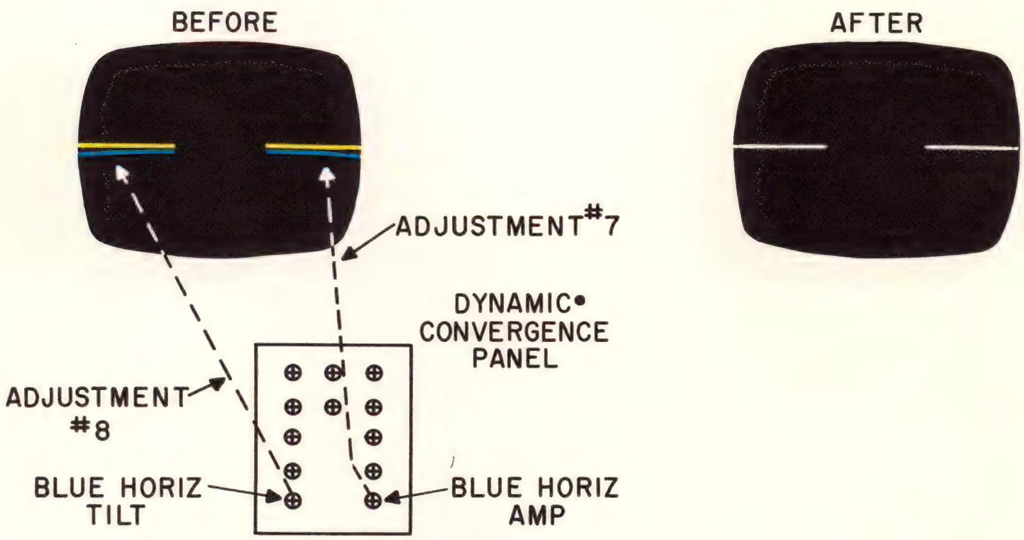


Figure 6-5. Adjustment of Blue Horizontal Dynamic Amplitude & Tilt Controls

are converged at all points along the vertical line, but are displaced vertically as shown in the expanded drawing to the left of the main drawing in Figure 6-3. Since red is converged on green along the vertical line, the error (in order to be visible) must be viewed on a short section of a horizontal line at the point it intersects the vertical line.

The next adjustments are the blue vertical "amplitude" and "tilt" adjustments. If the blue gun has been turned "off" during the preceding adjustments, it must be turned "on" by rotating the screen control clockwise.

The blue vertical amplitude and tilt controls are adjusted to converge blue on red-green by observing the horizontal lines near the top and bottom center of the screen. Again, it is necessary to view horizontal lines for adjustment, even though the misconvergence is caused by the vertical travel of the beams. Blue is converged along the vertical line, but is displaced vertically from red-green as shown in Figure 6-4. The geometry of the picture tube makes it necessary to observe two places, that is the top and bottom center of the screen as these two adjustments are made. The amplitude is adjusted and then the tilt, until blue is converged on red-green as indicated in Figure 6-4.

The remaining six adjustments are used to correct misconvergence caused by the horizontal travel of the beam. The adjustment procedure is quite similar to that used for the vertical dynamics; however, a different area of the screen is observed while making the adjustments.

The blue horizontal dynamic amplitude control is adjusted to converge blue on red-green, while observing the right end of a center horizontal line as shown in Figure 6-5. Blue horizontal tilt is then

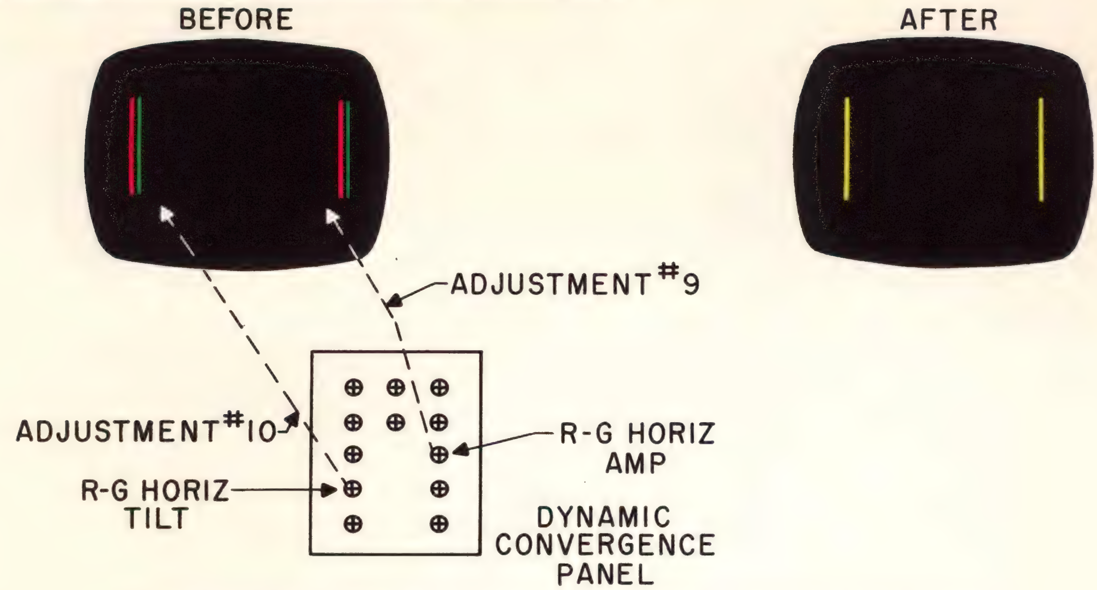


Figure 6-6A. Adjustment of R-G Horizontal Dynamic Amplitude & Tilt Controls

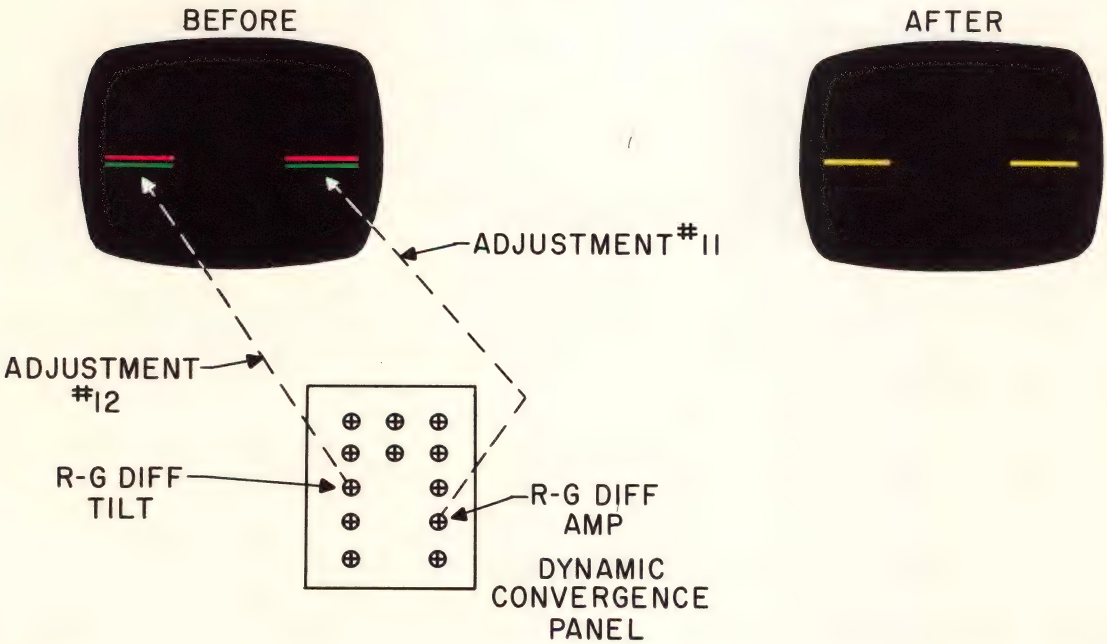


Figure 6-6B. Adjustment of R-G Horizontal Dynamic Differential Amplitude & Tilt Controls

adjusted to converge blue on red-green, while observing the left end of the center horizontal line.

The remaining four adjustments converge red on green, so the blue gun may again be turned "off" if desired.

The red-green amplitude is adjusted for convergence of red on green while viewing vertical lines on the right side of the screen and the red-green tilt is adjusted while viewing vertical lines on the left side of the screen as shown in Figure 6-6A.

The red-green differential amplitude control is adjusted to converge red on green while observing the ends of several horizontal lines on the right side of the screen. The red-green differential tilt is adjusted while observing the end of several horizontal lines on the left side of the screen as shown in Figure 6-6B.

Summary

The preceding section outlines the order of control adjustment and the area of the screen viewed during adjustment. This basic procedure should always be followed.

If the set is completely misconverged as it might be from replacing the picture tube or other major component, the convergence controls should be first adjusted to minimum or center of their range. A generator producing a cross-hatch pattern should be connected to the set. Following the outlined

procedure, each control should be adjusted for **approximate convergence.** The entire procedure should then be repeated adjusting each control for exact convergence. The preliminary adjustments will position each control, so that only minor changes will be required for final adjustment. This will minimize any interaction between the various controls and greatly add to the speed and ease of adjustment.

After the dynamic controls are adjusted, there are sometimes small convergence errors that can not be completely corrected with adjustments. These errors are caused by the field from the deflection yoke not acting equally on the three beams or the dynamic convergence waveforms not being exactly correct.

The final dynamic adjustments should be made to compromise any non-convergable errors and move them as near to the edge of the screen as possible. The errors that are non-convergable are normally quite small and will not be noticeable if moved to this area of the screen.

After the dynamic adjustments are properly set, the static magnets should be carefully adjusted for exact convergence at the center of the screen.